REVIEW AND EVALUATION OF URBAN FLOOD FLOW FREQUENCY PROCEDURES

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REVIEW AND EVALUATION OF URBAN FLOOD FLOW FREQUENCY PROCEDURES [1/]

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ABSTRACT

This report evaluates 128 published and unpublished papers (1962 to 1979) on urban flood flow frequency estimation procedures. It is a product of an ongoing project between the U.S. Department of Transportation, Federal Highway Administration and the U.S. Department of Interior, U.S. Geological Survey in cooperation with the U.S. Department of Agriculture, Science and Education Administration. The objective of this literature evaluation is to provide information on the types of methods being used to describe the effect of urbanization on flood runoff. Such information is useful in developing more accurate national or regional urban flood flow frequency estimation procedures.

The procedures are separated into three classes: (1) statistical estimation of peak flow, (2) single storm event, and (3) continuous record. Each article evaluated is presented in an appendix as follows: (1) bibliographic citation; (2) abstract, which may include a brief description of the procedure, form of the estimation equation, data requirements, description of the data base used for calibration, calibration results and informative comments; (3) classification of the procedure; and (4) location for which the procedure is applicable. The evaluation revealed that there were very few national or regional procedures in the statistical estimation of peak flow class.

1/ Contribution from the U.S. Department of Agriculture, Science and Education Administration, Agriculture Research, Hydrology Laboratory, Beltsville, Md., and the U.S. Geological Survey, Water Resources Division, Reston, Va.

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INTRODUCTION

Man's impact through urbanization causes a dramatic effect on the flood response of a watershed. The conversion from pervious to impervious surfaces typically inhibits infiltration and groundwater recharge and reduces surface roughness, surface retention, and depression storage. Thus, rainfall losses are reduced and direct storm runoff is increased. The alterations and improvements made to the existing drainage networks cause a more rapid runoff response because of increased flow velocities over smooth surfaces to drainage inlets and thence by pipe to improved natural channels. Usually, the introduction of impervious surfaces and improved drainage systems increases the amount of runoff and reduces flow travel times producing a flood hydrograph of increased magnitude that is quicker to rise and recede.

The changes in peak flow depend on many factors: the character of the natural flood response of the watershed, the extent and location of urbanization within the watersheds, the changes in watershed characteristics, the size of the watershed, and the severity of the storm event. This literature review supports the generally held concept that urbanizing a natural drainage basin usually causes runoff volume to increase and basin response time to decrease. In addition, peak discharges are generally increased for those watersheds which do not have significant in-channel or detention storage. Some aspects of urbanization, however can result in decreased flooding potential. For instance, if the lower part of the basin is urbanized and the upper part left in its natural condition, rapid removal of floodwaters from the lower part of the watershed may occur before the upper drainage can significantly contribute runoff to the lower reaches. Also, detention ponds, culverts, bridges, storm sewers, and roadway embankments may cause storage of runoff behind these structures that results in reduced peak-flow rates.

The relative significance of impervious area and channel improvement on flood response will vary with catchment size. Overland runoff in small catchments represents a significant proportion of total flow time. Therefore, the introduction of impervious surfaces, which increase the velocity of surface runoff and the response time, has a greater effect on flood volumes and peak discharge. Conversely, channel flow represents a larger proportion of total flow time in large catchments, and the major increase in response time may be due to channel improvement.

When the rainfall intensity exceeds the infiltration capacity of pervious surfaces, the runoff response may be similar to that of impervious surfaces. Therefore, an increase in impervious areas will cause less of an increase in flood levels for the more severe storms. Also, floods exceeding the capacity of the urban drainage system cause localized ponding that may reduce flood levels downstream.

The effects of urbanization on flood runoff are briefly discussed above to explain why results of different studies are often inconsistent or inconclusive and why present estimation procedures are not always transferable. This literature evaluation provides information on the types of models and model parameters being used to describe the effect of urbanization on flood runoff to aid in developing national or regional urban flood frequency procedures. This publication is a product of an ongoing urban flood frequency project of the Federal Highway Administration and the U. S. Geological Survey in cooperation with the USDA Science and Education Administration, for the purpose of: (1) reviewing literature of urban flood studies; (2) compiling a data base of flood frequency, topographic, physical, climatic, and land use characteristics on a variety of urban watersheds; and (3) analyzing the data for the purpose of developing estimating procedures that can be used in ungaged urban areas.

CLASSIFICATION SYSTEM

Given the large number of procedures that could be used to estimate flood peak discharge, potential users would benefit from a classification system that separates procedures by important procedure characteristics. The literature abounds with terminology, often based on elementary concepts of systems engineering, used to describe hydrologic procedures. Unfortunately, many of these terms, while descriptive, do not convey to potential users the important characteristics that would be useful in selecting one procedure from the many available. Terms like "deterministic", "linear", and "time-invariant" do not uniquely characterize a procedure so that a potential user would benefit by knowing these characteristics. For example, both easily applied empirical equations and complex hydrograph techniques may be labeled as "deterministic".

McCuen and Rawls[3/] in their literature review of flood frequency procedures for ungaged rural areas investigated classifying flood frequency procedures according to (1) characteristics of the transfer function, (2) method of calibration, and (3) input/output characteristics. The eight category classification system which they derived is as follows: (1) statistical estimation of peak flow (Q_p), (2) statistical estimation of moments, (3) index flood estimation, (4) estimation by transfer of peak flow (Q_p), (5) empirical equations, (6) single storm event--rain frequency runoff frequency, (7) multiple discrete events, and (8) continuous record. The procedures evaluated by McCuen and Rawls[3/] were easily identifiable as belonging to one of the eight categories.

After reviewing the urban flood frequency literature, we concluded that the McCuen and Rawls classification system included too many categories and categories not applicable to urban areas. In this literature evaluation urban

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[3/]McCuen, R. H., and W. J. Rawls. 1979. Classification and evaluation of flood flow frequency estimation techniques. Water Resour. Bull. 15(1): 88-93.

flood frequency procedures are classified as follows: (1) statistical estimation of peak flow (Q_p) (McCuen and Rawls' categories 1 to 5); (2) single storm event (McCuen and Rawls' category 6); and (3) continuous record (McCuen and Rawls' categories 7 and 8). The major difference in the three categories is that in category 1 a flood discharge of a given frequency is estimated by watershed, climatic and urban characteristics; while category 2 a single hydrograph is estimated from a design rainfall and the peak of the hydrograph is assumed to be some function of the rainfall frequency (usually equal to it); and category 3 the hydrograph is estimated for the entire year or for several runoff periods during the year and a frequency analysis is performed on the annual maximum for each.

LITERATURE REVIEW EVALUATION

In this literature review evaluation, both manual and computer searches were used. The computer data bases searched were those included in the Water Resources Scientific Information Center (WRSIC), National Technical Information Service (NTIS), and the USDA Science and Education Administration Service Current Awareness Literature Search. Also, announcements soliciting published or unpublished articles were sent to the following: American Society of Civil Engineers, American Water Resources Association, American Society of Agricultural Engineers, American Geophysical Union, state water resources centers, and state water agencies.

Some publications submitted for review were not evaluated because they were not applicable to the study. There were numerous publications describing the use of a procedure and because of time and personnel limitations not all of these were included in the evaluated. Publications applicable are given in the appendix. Generally, the following information is included for each publication: (1) bibliographic citation; (2) abstract, which may include a brief description of the procedure, form of the estimation equation, data requirements, description of the data base used for calibration, calibration results, and informative comments; (3) classification of the procedure; and (4) location for which the procedure is applicable. Procedures that could be classified in more than one category were classified in the category of most frequent use.

Table 1 summarizes the articles according to the classification system and table 2 separates the articles according to the location for which they were developed. Numerous publications described the use of more than one procedure, but only a few compared the results achieved by using the different procedures. Table 3 lists articles that include comparisons or evaluations of more than one procedure. Most comparisons involved procedures in the single event or in the continuous record classes and usually involved limited data.

Of the 128 published or unpublished articles reviewed in this literature evaluation, it was observed that the literature does not adequately reflect what procedures are currently being used. Instead, the literature contains many articles on experimental models that have been designed for a specific

region or a specific problem. Also, many of the single event and continous record models reported were modified versions of previously reported models. Most of the models in the single event and continuous record categories could be applied regionally or nationally; however, no models in the statistical estimation of peak flow category (Q_p), except perhaps the rational formula, had regional or national applicability.

Table 1.--Summary of articles by category

Category	Publication No. in Appendix
1. Statistical estimation of peak flow (Q_p)	1,2,3,4,10,15,27,28,30,33,35,36,41,42,48,53, 56,57,60,61,64,65,67,69,71,74,77,78,80,83,87, 89,90,93,98,99,103,106,107,121,123
2. Single storm event	5,6,7,8,9,11,12,13,14,16,18,19,23,24,31,32,34, 37,38,40,43,45,46,54,55,58,59,62,63,66,70, 72,73,75,76,79,81,82,84,85,86,88,91,94,95,96, 97,100,104,105,108,109,110,111,112,113,114,115 116,118,119,120,122,124,125,126,128
3. Continuous record	8,17,21,22,25,26,29,49,50,51,52,68,92, 101,102,117
4. Assessment of data	20,39,44,47,127

Table 2.--Summary of articles by location

Location	Publication No. in Appendix
Entire United States	2,5,22,24,25,26,31,42,43,49,69,73,84,89,112, 113,114,115,126
Eastern United States	33
Northeastern United States	103
Alabama	41,82
Arizona	53,82,128
California	20,29,44,51,67,82,96
Colorado	54,82,94,125
Connecticut	120
Florida	54,82
Georgia	36,52,57,68,82
Hawaii	66

Table 2.--Summary of articles by location--continued

Location	Publication No. in Appendix
Illinois	1,14,17,18,59,70,74,82,85,100,110,111
Indiana	97
Iowa	21,63
Kansas	86
Kentucky	14,30,37,82
Louisiana	82
Maryland	3,14,15,50,74,77,88,99,110,127
Massachusetts	28,82,91
Michigan	14,33,82
Minnesota	76,82
Mississippi	33,54,123
Missouri	35,48,82,106
Nebraska	55,108
Nevada	82
New Jersey	107
New York	82
North Carolina	71,75,87
Ohio	82,85
Oklahoma	7,58,82,98,122
Oregon	60,82
Pennsylvania	4,39,64,82
Rhode Island	28
Tennessee	8,10,82,121
Texas	6,14,27,32,33,40,56,65,77,79,82,92,97,102
Utah	82,101
Virginia	3,15,34,50,72,93
Washington	60,61,82
Washington, D.C.	3,15,82,104
Wisconsin	54,75,82,117
Puerto Rico	13
Australia	45
Canada	70,119
England	9,19,38,83,95,109,118
France	105
Germany	124
New Zealand	78,80
Location not specified	11,12,16,23,46,47,62,81,90,116

Table 3.--List of articles comparing procedures

Publication No. in Appendix	Author(s)	Location	Year
6	Bailey and others	Texas	1975
7	Beard	Oklahoma	1978
11	Brandstetter	Not Specified	1976
18	Chow	Illinois	1976
20	Colyer and Pethick	England	1976
37	Haan	Kentucky	1975
45	Heeps and Mein	Australia	1974
54	Jennings and Mattraw	Colorado, Florida, Mississippi and Wisconsin	1976
57	Jones	Georgia	1978
70	Marsalek and others	Illinois and Canada	1975
85	Papadakis and Preul	Illinois and Ohio	1973
122	Williams	Oklahoma	1979

APPENDIX - LITERATURE EVALUATIONS

1. Allen, H. E., Jr., and R. M. Bejcek. 1979. Effects of urbanization on the magnitude and frequency of floods in northeastern Illinois. U.S. Geolog. Survey (Champaign, Ill.), Water Resour. Invest. 79-36, 48 pp.

Abstract: Techniques are presented for estimating the magnitude and frequency of floods in the urban environment of northeastern Illinois, and for estimating probable changes in flood characteristics that may be expected to accompany progressive urbanization. Suggestions are also offered for estimating the effects of urbanization on flood characteristics in areas other than northeastern Illinois. Three variables--drainage area, channel slope, and percent imperviousness (an urbanization factor)--are used to estimate flood magnitudes for frequencies ranging from 2 to 500 years. Multiple regression analyses were used to relate flood-discharge data to the above watershed characteristics for 103 gaged watersheds. These watersheds ranged in drainage area from 0.07 to 630 square miles in channel slope from 1.1 to 115 feet per mile, and in imperviousness from 1 to 39 percent.

Classification: Statistical estimation of peak flow.

Location: Northeastern Illinois.

2. American Society of Civil Engineers. 1975. Residential storm water management. 64 pp. New York, N.Y.

Abstract: Covers all aspects of storm water management. For peak flow the rational formula is described in detail. Tables of urban C values are presented.

Classification: Statistical estimation of peak flow.

Location: Entire United States.

3. Anderson, Daniel G. 1970. Effects of urban development on floods in northern Virginia. U.S. Geolog. Survey (Arlington, Va.), Water Supply Paper 2001-C, 22 pp.

Abstract: Relations are presented to estimate the magnitude of floods having recurrence intervals ranging up to 100 years for drainage basins with various degrees of urban or suburban development. The relations are based upon analysis of flood information of 81 sites, 59 of which are in the Washington, D.C. metropolitan area. The general form of the equation is

$$Q_x = \overline{Q}R = 230KRA^{0.82}T^{-0.48}$$

WHERE: Q_x = the magnitude of a flood of x-year recurrence interval in cubic feet per second

$\overline{Q}$ = the magnitude of the average flood in cubic feet per second

R = the flood-frequency ratio based upon interpolation between ratios for natural flow runoff and those for 100 percent impervious conditions derived from rainfall frequencies

230 = factor related to rainfall and soil conditions in Northern Virginia area -- determined by regression analysis

K = the coefficient of imperviousness computed from the equation

$$K = 1.00 + 0.015I$$

where I = percentage of basin area covered with impervious surface (R. W. Carter)

A = basin area in square miles

T = lag time in hours determined from the equation:

$$T = C_1 (L \sqrt{S})^{C_2} \text{ where}$$

C_1 C_2 = constants dependent upon degree of basin development

L = basin length

S = basin slope

The method of analysis is considered to be general and may be used for any area where the major floods result from rainfall.

Classification: Statistical estimation of peak flow.

Location: Maryland, Northern Virginia, and Washington, D.C.

4. Aron, F., D. F. Kibler, and C. J. Tagliati. 1978. The development of flood-potential index maps for Pennsylvania. Pa. State Univ. (University Park), Inst. for Res. on Land and Water Resour.

Abstract: Flood-potential index maps were developed for Pennsylvania. Flood indices were computed for gaged watersheds by dividing the 100-year and 2.33-year flood peaks by the watershed area contributing to flooding. It was found that $Q^{2.33}$ is proportional to $A^{0.8}$ and Q^{100} is proportional to $A^{0.7}$. Flood indices were plotted on maps broken down into three area ranges and two return periods. A procedure was developed using the flood-potential index maps to estimate peak floods for ungaged watersheds. The square of the inverse distance to nearby flood index location is used as a weighting factor. The flood index is estimated for the 100-year and the 2.33-year return period and the corresponding flood peaks are computed. A nomograph is provided to obtain flood peaks for return periods between the 2.33- and the 100-year periods. A preliminary study of the effect of urbanization on flood peaks was also made. Population density was used as a parameter in the correction of flood indices.

Classification: Statistical estimation of peak flow.

Location: Pennsylvania.

5. Aron, G., and Lakatos, D. F. 1976. Penn State urban runoff model user's manual. Pa. State Univ. (University Park), Inst. for Res. on Land and Water Resour. Res. Pub. 96, 74 pp.

Abstract: The Penn State urban runoff model is an alternative to the traditional rational methods and other semi-empirical procedures for urban drainage design. The model simulates overland flow, pipe flow, and surcharge flow at a draining inlet and allows analysis of the timing of subarea flow contributions to peak rates at various points in a watershed. The SCS curve number runoff procedure is used in overland flow runoff calculations. Mannings equation is used for sewer flow and Muskingum method for reservoir routing. A complete description of how to use the model is included.

Classification: Single storm event.

Location: Entire United States.

6. Bailey, B. H., R. H. Ramsey, B. J. Claborn, R. M. Sweazy, and D. M. Wells. 1975. Variation of urban runoff quality and quantity with duration and intensity of storms. Phase III, Vol. 3, Analysis of Flow Models. Tex. Tech. Univ. (Lubbock), Water Resour. Center, OWRT Report W76-08280, 32 pp.

Abstract: Runoff events from a 1,499 acre urban watershed in Lubbock, Tex., were monitored over a 9-month period from September 1974 to May 1975. The observed peak flows and runoff volumes were compared with the outputs generated from four runoff models which used the precipitation records and watershed characteristics as inputs. The following models were used: Rational, Viessman, Keating, Srinivasa, Viessman and Miller, and the British Road Research Laboratory (RRL). For the study data, the Viessman, Keating, and Srinivasa method yielded a correlation of 0.91 to best predict the total runoff from a precipitation event. The RRL method had a correlation

coefficient of 0.45 the best in predicting the peak rates. By using observed flow volumes and peak rates of flow as reference values, the outputs from the various models were compared to determine how conservative the models were in predicting peak rates of flow and runoff volumes.

Classification: Single storm event and comparison.

Location: Lubbock, Tex.

7. Beard, L. R. 1978. An urban runoff model for Tulsa, Okla. Tex. Univ. (Austin), Dept. of Civil Engin., Tech. Rpt. CRWR-160, 201 pp.

Abstract: Twenty-five hydrologic models which could be used to adjust flood flows for the effects of urbanization in Tulsa, Okla., were reviewed. The HEC-1 model was chosen and was calibrated to urban conditions. Guidelines are given for adjusting model parameters for urban effects.

Classification: Single storm event and comparison.

Location: Tulsa, Okla.

8. Betson, R. 1976. Urban hydrology: A systems study in Knoxville, Tenn. Tenn. Valley Author. (Knoxville), Div. of Water Managt., 138 pp.

Abstract: Two models, a continuous daily streamflow model and a storm hydrograph model, were modified to handle urban conditions. The continuous streamflow model is basically a simple water budget bookkeeping for the watershed where daily rainfall is budgeted among a series of conventional cascading compartments. The algorithm developed by Miller and Viessman in 1972 for predicting storm runoff from urban areas was incorporated into the model to handle urban conditions. This algorithm determines the impervious area runoff directly based with the portion of the watershed that is impervious using the following equation:

Impervious area runoff = residual rain x 1.165 x(1% impervious -0.17).

The hydrograph model uses the SCS curve numbers and a measure of the extent of the area sewered (Espey and Winslow) to describe the urban area. These models were tested on four watersheds in the Knoxville area.

Classification: Continuous record and single storm event.

Location: Knoxville, Tenn.

9. Bleek, J. 1975. Synthetic unit hydrographs in urban hydrology. In National Symposium on Urban Hydrology and Sediment Control, Univ. Ky. (Lexington) Bull. 109, pp. 149-159.

Abstract: Two synthetic unit hydrograph approaches were used. First relating unit hydrograph characteristics directly to catchment parameters and second,

correlating the coefficients of a linear conceptual model with catchment and storm parameters. Both techniques were applied to a catchment in southeast England. The parameter used to describe urbanization in both models was the percent imperviousness.

<u>Classification</u>: Single storm event.

<u>Location</u>: England.

10. Boning, C. W. 1977. Preliminary evaluation of flood frequency relations in the urban areas of Memphis, Tenn. U.S. Geolog. Survey (Nashville, Tenn.), Water Resour. Invest. 77-132, 50 pp.

<u>Abstract</u>: A storm runoff relation for streams in the urban areas of Memphis was determined by a statistical evaluation of 59 flood discharges from 19 gaging stations. These flood discharges were simulated by using multiple regression analysis and the variables drainage area, percent imperviousness of the drainage basin, and the maximum rainfall occurring over 120-minute periods for a given storm. The defined relation is:

$$Q = 158.3A^{.777A^{-.02}} \quad (IMP+1)^{.227}(I120)^{.539}(I120)^{.40}$$

where Q is flood discharge in cfs, A is drainage area in square miles, IMP is percent imperviousness in the basin, and I120 is the maximum rainfall in inches, over a 120-minute time period.

The defined relation was used to synthesize sets of annual flood peaks for drainage basins ranging from 0.05 square miles to 10 square miles and imperviousness ranging from 0 to 80 percent for the period of rainfall record at Memphis. From these series of flood peaks, flood discharges were defined and presented for 2-, 5-, 10-, 25-, 50-, and 100-year recurrent intervals and related to drainage area in square miles and the percent of watershed impervious.

<u>Classification</u>: Statistical estimation of peak flow.

<u>Location</u>: Memphis, Tenn.

11. Brandstetter, A. 1976. Assessment of mathematical models for storm and combined sewer management. Battelle Pacific Northwest Lab. (Richland, Wash.), EPA-600/2-76-17a, 510 pp.

<u>Abstract</u>: Mathematical models for the nonsteady simulation of urban runoff were evaluated to determine their suitability for the engineering assessment, planning, design, and control of storm and combined sewerage systems. The 11 models evaluated solely on the basis of published information in reports by model builders and model users were: British Road Research Laboratory Model, Chicago Hydrograph Method, Colorado State University Urban Runoff Modeling, Corps of Engineers Hydrologic Engineering, Center STORM Model, Hydrocomp Simulation Program, Minneapolis-St. Paul Urban Runoff Model, Seattle Computer Augmented Treatment and Disposal System, University of Cincinnati Urban Runoff

Model, University of Illinois Storm Sewer System Simulation Model, University of Massachusetts Urban Runoff Model and Wilsey & Ham Urban Watershed Model. The seven models also tested by computer runs were: Battelle Urban Wastewater Management Model, Dorsch Consult Hydrograph-Volume Method, Environmental Protection Agency Stormwater Management Model, Massachusetts Institute of Technology Urban Watershed Model, Metropolitan Sanitary District of Greater Chicago Flow Simulation Program, SOGREAH Looped Sewer Model, and Water Resources Engineers Stormwater Management Model. A review of all 18 models is presented in the report, which includes a summary description of each model, a list of the phenomena considered, brief outlines of the mathematical formulations with comments on their advantages and shortcomings, and comments on the computer program and output options. The theoretical background equations of the seven models selected for numerical testing are presented. The hypothetical and real catchment data used for the numerical testing and the numerical results and evaluations are given.

Classification: Single storm event and comparison.

Location: Not specified.

12. Brandstetter, A., R. L. Engel, and D. B. Cearlock. 1973. A mathematical model for optimum design and control of metropolitan wastewater management systems. Water Resour. Bull. 9(6): 1188-1200.

Abstract: The Battelle Urban Wastewater Management Model is intended primarily for the simulation of major sewer system components, such as trunk and interceptor sewers, regulators, overflow storage facilities, and treatment plants. Catchments are represented by their areas and the length of the main drainage channel; catchment shape does not enter the computations. Overland flow and flow routing in gutters and minor channels are lumped into a single computation. Losses from impervious areas, such as wetting of surfaces and retention by storage in depressions, are assumed to decay exponentially with time as a function of catchment moisture conditions after an initial loss is satisfied. Losses from pervious areas include infiltration and the losses considered for impervious areas. They are approximated by a modified Holtan infiltration equation which considers an initial loss that must be satisfied and treats infiltration as a function of soil-moisture content. The excess precipitation is convoluted with a unit hydrograph to determine the storm runoff from each catchment. The unit hydrographs are derived for ungaged catchments by a method developed by the Soil Conservation Service. They are computed by using the physical catchment characteristics which include drainage area, length, slope, soil, and vegetation. The flow routing is accomplished by the kinematic wave formulation of the equations of motion. The equations consist of the nonsteady equation of continuity, Manning's equation to define the energy gradient, and relationships based on the geometry of circular pipes.

Classification: Single storm event.

Location: Not specified.

13. Bras, R. L., and F. E. Perkins. 1975. Effects of urbanization on catchment response. Amer. Soc. Civil Engin., Jour. Hydraul. Div. 101(HY3): 451-466.

Abstract: A very detailed model of urban catchments utilizing the kinematic wave representative of the one dimensional equations of motion. The resulting momentum and continuity equations are solved by finite difference techniques to simulate flow in a conceptual basin represented by a network of overland stream, pipe, and gutter segments. Infiltration is represented by Horton's equation. From the detailed model a simple model was developed based on an adjustment of rainfall intensities to account for imperviousness and an averaging of roughness coefficients in a simple aggregated representation of the area.

Classification: Single storm event.

Location: Puerto Rico.

14. Brater, E. G., and J. D. Sherrill. 1975. Rainfall-runoff relations on urban and rural areas. U.S. Environ. Protec. Agency (Cincinnati, Ohio.), Nat. Environ. Res. Center, 95 pp.

Abstract: A unit hydrograph procedure is given for determining the frequency of storm runoff on small drainage basins (less than 20 square miles). The method is calibrated by using 1,620 storm events on 69 basins in Texas, Michigan, Kentucky, Illinois, and Maryland. The form of the unit hydrograph is related to drainage basin size and the degree of urbanization, as measured by population density. Infiltration and retention are accounted for, with infiltration varying seasonally. The percent impervious area was found to be linearly related to population density.

Classification: Single storm event.

Location: Illinois, Kentucky, Michigan, Maryland and Texas.

15. Carter, R. W. 1961. Magnitude and frequency of floods in suburban areas. U.S. Geolog. Survey (Arlington, Va.), Prof. Paper 424-B, 11 pp.

Abstract: The effect of urban development on floods in the vicinity of Washington, D.C., with a recurrence interval of 2.33 years is evaluated through the use of the following equations:

$$\overline{Q}/K = 223A^{0.85}T^{-0.45}$$

Where:

$\overline{Q}$ = the flood discharge in cubic feet per second which corresponds to a recurrence interval of 2.33 years.

$K = \frac{0.30 + 0.0045I}{0.30}$ + the factor by which all flood peaks are increased by the percent of impervious Area I.

A = drainage area in square miles.

T = lag time defined by equation $T = C\,(L/\sqrt{S})^{0.6}$

Where: C = constant dependent upon development of basin

L = total length from the gaging point to the rim of the basin measured along the principal channel

S = weighted slope of an order of 3 or greater of all stream channels in the basin.

Classification: Statistical estimation of peak flow.

Location: Maryland, Northern Virginia, and Washington, D. C.

16. Chien, Jong-Songm, and K. K. Saigal. 1974. Urban runoff by linearized subhydrographic method. Amer. Soc. Civil Engin., Jour. Hydraul. Div. 100(HY8): 1141-1157.

Abstract: The development of a simple hydrograph method is presented. The linearized subhydrographs method utilizes functional relationships between rainfall and runoff. The parameters used in this method include time of concentration and runoff coefficient. Along with functional development, test applications are also examined. In two typical storms applied, time synchronization and rate of runoff predicted are in good agreement with the recorded hydrographs.

Classification: Single storm event.

Location: Not specified.

17. Chicago, City of. 1972. Development of a flood control and pollution control plan for the Chicagoland area. City of Chicago, Bureau of Engineering, Department of Public Works, with Metropolitan Sanitary District of Greater Chicago and Illinois Institute for Environmental Quality, Computer Simulation Programs, Technical Report Part 2.

Abstract: The Chicago runoff and pollution model was developed by the City of Chicago Department of Public Works for the continuous simulation of the time-varying runoff and water quality in combined sewerage systems consisting

of several catchments and a converging branch sewer and open channel network. The rainfall-runoff and flow routing portions of the model use methods included in the computer version of the Chicago hydrograph method.

Classification: Continuous record.

Location: Chicago, Ill.

18. Chow, V. T., and B. C. Yen. 1976. Urban storm water runoff: Determination of volumes and flowrates. Dept. of Civil Engin., Ill. Univ. (Champaign), EPA 160012-76/116.

Abstract: An investigation was made to compare and evaluate selected urban stormwater runoff prediction methods. The eight methods evaluated are the rational method, unit hydrograph method, Chicago hydrograph method, British transport and road research laboratory method, University of Cincinnati urban runoff method, Dorsch hydrograph volume method, Environmental Protection Agency storm water management model, and Illinois urban storm runoff method.

The comparison and evaluation are done by using four recorded hyetographs of the Oakdale Avenue drainage basin in Chicago to produce the predicted hydrographs by the methods and the results are compared with recorded hydrographs. The relative merits of the methods are discussed and recommendations are made.

Classification: Single storm event and comparison.

Location: Chicago, Ill.

19. Colyer, P. J., and R. W. Pethick. 1976. Storm drainage design methods - a literature review. Hyraul. Res. Sta. Rpt. (Wallingford, England) INT 154, 86 pp.

Abstract: Literature relating to the design of urban storm drainage systems was reviewed. The review describes the historical development of the types of storm drainage and the formulation of design methods. Some 20 available design methods are outlined, and comments are made on their calculation procedures. The models were Rational (Lloyd-Davies) methods, Inlet method, Time-area methods, Sarginson's method, Unit hydrograph methods, Dimensionless hydrograph methods, Transport and Road Research Laboratory (TRRL) method, Illinois Urban Drainage Area Simulator (ILLUDAS), Los Angeles hydrograph method, Chicago hydrograph method, Massachusetts Institute of Technology (MIT) method, University of Cincinnati Urban Runoff (UCUR) model, Hydrologic Simulation Program (HSP), Battelle Urban Wastewater Management model, Hydrograph Volume Method (HVM), Environmental Protection Agency Storm Water Management Model (SWMM), Illinois Storm Sewer System Simulation (ISS) model, and Sogreah method. For each method, brief information is given concerning its authorship and background, general characteristics, calculation procedure, data and computational requirements, and performance. The performance of the models was assessed on the basis of their accuracy in reproducing observed rainfall-runoff events. Published testing of the methods was also reviewed.

Classification: Single storm event and comparison.

Location: England.

20. Crippen, J. R., and Waananen, A. O. 1969. Hydrologic effects of suburban development near Palo Alto, Calif. U.S. Geolog. Survey (Menlo Park, Calif.), Open-file Rpt., 126 pp.

Abstract: Data were gathered for 7 years in three small basins in the foothills west of San Francisco Bay near Palo Alto, Calif., to detect changes in the hydrologic regime caused by suburban development. The authors did not put forth any method for calculating the effect of urbanization on runoff or peak flows although they did notice that T_{50} or time from centroid of excess precipitation to passage of 50 percent of runoff changed from $T_{50} = 3.70 (L/S)^{0.6}$ before development to $T_{50}=2.60 (L/S)^{0.6}$ after development, where "L" and "S" are indices of channel length and slope. It was observed that urbanization led to an increase in flood flows of low magnitude and a much smaller change in the number of higher peaks, but no method of predicting the change was presented.

Classification: Assessment of data.

Location: Palo Alto, Calif.

21. Croley II, T. E., and J. R. Barnard. 1976. Ralston Creek flooding induced by South Branch urbanization. In National Symposium on Urban Hydrology, Hydraulics, and Sediment Control, Ky. Univ. (Lexington) Bull. 111, pp. 257-271.

Abstract: The Stanford Watershed Model, University of Kentucky version, as developed for small watersheds by Ohio State University is used by the authors to evaluate urban floods on Ralston Creek in Iowa. The model requires hourly precipitation, daily runoff, evaporation, extreme temperature data, as input. Watershed characteristics are used to estimate the model parameters for urban conditions.

Classification: Continuous record.

Location: Iowa City, Iowa.

22. Curtis, D. C., and G. F. Smith. 1976. The National Weather Service River forecast system update 1976. National Weather Service, (Silver Spring, Md), Hydrol. Res. Lab. Rpt. 23, 14 pp.

Abstract: The National Weather Service River Forecast System, which is a continuous simulation model, is described. The program has a modular structure so components can be added, dropped, or modified at any time. Because the publication does not provide all information, the National Weather

Service should be contacted for current information on components and uses. The Sacramento River Forecast Model is used for soil moisture accounting.

Classification: Continuous record.

Location: Entire United States.

23. DaCosta, P. C. C. 1970. Effect of urbanization of storm water peak flows. Amer. Soc. Civil Engin., Jour. Sanit. Engin. Div., 5 pp.

Abstract: Starting with a basic, synthetic, or characteristic hydrograph of natural watershed and using true rational relationships between rainfall and runoff, it is possible to modify the hydrograph and the corresponding peak discharge according to the degree of urbanization, as expressed by the degree of imperviousness and the degree of artificial channelization given to the watershed. Practical applications of those relationships may require much experimental data and the control with other methods of calculating urban and natural runoffs. By using the rational formula Q = CIA, the author determined different values for "C" depending upon degree of imperviousness. He also discussed the change in lag time caused by urbanization accompanied by sewer or lined channel installation.

Classification: Single storm event.

Location: Not specified.

24. Danner, D., G. Evereklian, and L. Noll. 1974. Characteristic urban hydrograph model. Catholic University of America, Washington, D.C.

Abstract: The triangular hydrograph was used to model urban runoff. The formulation of the hydrograph parameters were based on area, length of the watershed, slope between the most remote point in the watershed and the outlet, Manning n, and characteristic depth of flow. The urban hydrograph can be summarized in three governing equations:

$$Q_m = \frac{C\ i\ A}{T_c}$$

$$T_c = K_u \ \frac{L^{1.5}}{H^{1/2}}$$

$$K_u = \frac{n}{1.49 \ \times \ (df)^{2/3}}$$

where Q_m = peak flow in cubic feet per second; C = runoff coefficient (rational); i = rainfall intensity in inches per hour; A = area of urban watershed in square miles; T_c = time of concentration in hours; K_u = characteristics urban time constant; L = distance from remotest point to the outlet in feet; H = elevation of the remotest point above the outlet in feet; df = characteristic depth of flow $=(Vn/(1.49s^{0.5}))^{1.5}$; s = slope; and v = velocity.

Classification: Single storm event.

Location: Entire United States.

25. Dawdy, D. R., R. W. Lichty, and J. M. Bergmann. 1972. A rainfall-runoff simulation model for estimation of flood peaks for small drainage basins. U.S. Geolog. Survey (Washington, D. C.), Prof. Paper 506-B, 28 pp.

Abstract: Application of the USGS watershed model which uses data from a point rainfall gage and daily evaporation to predict peak flow and flood volume for a continuous period is discussed. Soil moisture is modeled as two layer system. Philip's infiltration equation is used to infiltrate water into the top layer. The model can handle both impervious and pervious areas.

Classification: Continuous record.

Location: Entire United States.

26. Dawdy, D. R., J. C. Schaake, Jr., and W. M. Alley. 1978. Users guide for distributed routing rainfall-runoff model. U.S. Geolog. Survey (Reston, Va.), Water Resour. Invest. 78-80, 151 pp.

Abstract: A computer program of a watershed model for routing urban flood discharges through a branched system of pipes or natural channels using rainfall as input has been developed and documented. The model combines soil-moisture-accounting and rainfall-excess components with the kinematic-wave routing method.

Classification: Continuous record.

Location: Entire United States.

27. Dempster, G. R., Jr. 1974. Effects of urbanization on floods in the Dallas, Tex., metropolitan area. U.S. Geolog. Survey, (Austin, Tex.), Water Resour. Invest. 60-73, 51 pp.

Abstract: The collection of streamflow and rainfall data in and near Dallas, Tex., during the period 1962-70 afforded a definition of some of the hydrologic effects attributable to urban development. A digital model of streamflow response to rainfall and evaporation input was calibrated for watersheds with different degrees of urban development as reflected by impervious area. The rainfall-runoff relations were used with a 57-year record of rainfall to simulate annual peak discharges at 14 sites. Frequency curves were then prepared from these peak discharges; and from these, the discharges corresponding to recurrence intervals of 1.25, 2, 5, 10, 25, 50 and 100 years were obtained. The discharges at these recurrence intervals were related to drainage area, length-root slope ratio, and coefficient of impervious area by multiple regression techniques in the form of a power equation. Simplified equations using only drainage area and the coefficient of impervious area were also presented. Observed peak discharges and flood

volumes were compared with those computed by the model. For the control basins (those for which observed flood-volume data were available to derive moisture-accounting parameters), the average standard error for simulated flood peaks was 26 percent. For the noncontrol basins (those in which moisture-accounting parameters were estimated from the parameters derived for the control basins), the average standard error was 46 percent.

Classification: Statistical estimation of peak flow.

Location: Dallas, Tex.

28. Doehring, D. O., and Smith, M. E. 1978. Modelling the dynamic response of floodplains to urbanization in eastern New England. U.S. Dept. Int. (Washington, D.C.), Off. Water Res. and Tech., 93 pp.

Abstract: Data from 18 watersheds located in eastern Massachusetts and Rhode Island are used to develop a methodology whereby the change in discharge corresponding to both 1 and 2 percent annual exceedance probabilities may be predicted. Topographic maps, surficial geologic quadrangles, and land use maps are employed to develop indices of urban land use change, surficial watershed properties and drainage network configuration. The dependent variable is derived from two separate estimates of flood expectancy which are found by standard analyses of nonoverlapping segments of a basin's hydrologic record. Multiple regression techniques have yielded two equations corresponding to the 50-year and 100-year flood expectancies. The urbanization index is by far the most important predictor, although the network parameter and the pervious index contribute substantially to the model.

Classification: Statistical estimation of peak flow.

Location: Massachusetts and Rhode Island.

29. Durbin, T. J. 1975. Selected effects of suburban development on runoff in south-coastal California. In National Symposium on Urban Hydrology and Sediment Control, Ky. Univ. (Lexington) Bull. 109, pp. 209-219.

Abstract: The Stanford watershed model was used to simulate the effects of suburban development on the runoff from five drainage basins in the south-coastal area of California. The drainage basins ranged in size from 3.72 to 83.4 square miles. By using the model, synthetic records of runoff for each basin were generated to represent various degrees of suburban developmemt. Examination of the synthetic records indicated that suburban development has the following effects on flood frequency: (1) Suburban development can increase the magnitude of peak discharge with a recurrence interval of 2 years by a factor of three to six and (2) peak discharges that have recurrence intervals greater than a limiting value ranging from 50 to 200 years or more are little affected by suburban development.

Classification: Continuous record.

Location: California.

30. Eagleson, P. E. 1962. Unit hydrograph characteristics for sewered areas. Amer. Soc. Civil Engin., Jour. Hydrau. Div. 88(HY2): 1-23.

Abstract: Hydrographs of measured storm sewer outflow from urban areas up to 7.5 sq mi were analysed. The characteristics of the hydrographs were correlated with mean basin slope and percent imperviousness. A design procedure is outlined.

Classification: Statistical estimation of peak flow.

Location: Louisville, Ky.

31. Espey, W. H. Jr., D. G. Altman, and C. B. Graves, Jr. 1977. Nomographs for ten-minute unit hydrographs for small urban watersheds. Amer. Soc. Civil Engin. (New York, N. Y.), Urban Water Resour. Res. Program Tech. Memo. No. 32, 22 pp.

Abstract: The five hydrologic parameters that describe the fundamental shape of the 10-minute unit hydrograph were developed from rainfall-runoff data collected for 41 small watersheds throughout the United States. The watersheds range in size of drainage area between 0.014 and 15.0 square miles. The physiographic parameters used to describe the watershed are: size of drainage area; main channel length; main channel slope; extent of impervious cover; and a dimensionless watershed conveyancy factor. The conveyancy factor is the description of the conveyance efficiency of the watershed's drainage system. The basic drainage system conditions that effect the coveyance efficiency or hydraulic response of an area can be evaluated in terms of this factor. These basic drainage system conditions include degree of main channel improvement, upstream main channel roughness coefficient (Manning 'n'); storm sewer density, area or length of streets, and amount of impervious area. The hydraulic response of a watershed is a function of the drainage efficiencies of both the main channel and contributing subareas, respectively described by a weighted Manning 'n' value and percent impervious cover. Regression analysis was used to relate the unit hydrograph parameters to physiographic characteristics.

Classification: Single storm event.

Location: Entire United States.

32. Espey, W. J. Jr., C. W. Morgan, and D. E. Winslow. 1969. Urban effects on the unit hydrograph. In Effects of watershed changes on streamflow, water resources symposium No. 2, Tex. Univ. (Austin), Center for Res. Water Resour., pp. 215-228.

Abstract: A summary of previous work concerning peak floods for urban areas in Houston, Tex., are presented. Logarithmic form of multiple regression, equations defining lag time and peak flow based on watershed area, length of the main channel, slope of the main slope, percent of impervious cover, and a channel roughness factor are developed. The channel roughness factor was related to channel improvements and channel vegetation. From these studies it is noted that increased urbanization results in increased peak flows and accentuated high and low flows. From equations presented it is predicted that peak flows may be expected to increase from two to four times that of the flow from the underdeveloped watersheds, depending upon the type of channel improvement, amount of vegetation in the channel, and the type of secondary drainage system. The capacity of the secondary drainage facilities may have a limiting effect on the peak discharge.

Classification: Single storm event.

Location: Houston, Tex.

33. Espey, W. H., Jr., and D. E. Winslow. 1974. Urban flood frequency characteristics. Amer. Soc. Civil Engin., Jour. Hydraul. Div. 100(HY2): 279-293.

Abstract: Flood-frequency analysis of 60-small urban watersheds (27 in Texas, 26 on the East Coast, 2 in Michigan, 1 in Illinois, and 4 in Mississippi) are presented. Data from these watersheds were used to develop equations of the logarithmic form of the multiple regression using drainage area, slope, impervious cover, and a channel roughness factor to predict the peak flow for a specific recurrence interval. The average absolute error of the equations was about 30 percent. The derived equations for all 60 urban watersheds were used to predict the peak flows for specific return periods for 2 independent urban watersheds not used in the derivation of the equations; on one of these, the equations consistently predicted high (averaging 30 percent), and on the other, better agreement was obtained. The average error being approximately 10 percent. Studies were also performed on watersheds in Austin and Houston, Tex. In Austin the flood discharge, due to urbanization, was significantly increased to a peak at 2 to 5 years followed by a decreasing effect. In Houston it was also noted that urbanization significantly increased the peak discharge.

Classification: Statistical estimation of peak flow.

Location: Eastern United States, Illinois, Michigan, Mississippi, and Texas.

34. Fitch, W. N., J. P. Hartigan, and M. L. Iwanski. 1976. Urban flooding response to land use change. In National Symposium on Urban Hydrology, Hydraulics, and Sediment Control, Ky. Univ. (Lexington) Bull. 111, pp. 271-287.

Abstract: The effect of changing land use on the frequency and severity of urban flooding has been studied in the area of Four Mile Run, a small urban watershed (19.5 sq. mi.) in metropolitan northern Virginia. The approach used was to develop a design storm which will reproduce the 100-year flood event

upon which the flood control project is based. Design hydrographs for 179 drainage areas are developed by simulating the flood event with the modified stormwater management model (WREM) developed by Water Resources Engineers, Inc. The model portrays a runoff system feeding a transport system. The transient flow equations are solved by finite difference techniques. Soil, land use, and impervious data are developed for each drainage area from available maps and aerial photographs. Three calibration storms are selected on the basis of the availability of rainfall and runoff data. Each storm is simulated in detail by constructing five to seven rainfall records in 15-minute intervals. These rainfall records and supporting data, including land use data corresponding to the rainfall data time period, are used in the model in order to produce runoff hydrographs that matched those actually observed.

Classification: Single storm event.

Location: Northern Virginia.

35. Gann, E. E. 1971. Generalized flood-frequency estimates for urban areas in Missouri. U.S. Geological Survey (Rolla, Mo.), Open-file Report, 18 pp.

Abstract: A method is presented for estimating flood-frequency information for urban areas in Missouri. Flood-frequency relations are presented which provide an estimate of the flood-peak discharge for floods with recurrence intervals from 2.33 to 100 years for basins with various degrees of existing or projected urban development. Drainage area sizes for which the relations are applicable range from 0.1 to 50 miles. The peak flow relationships developed were the logarithmic form of the multiple regression with the independent parameters being drainage area, basin slope, a ratio of discharge after urbanization to discharge before urbanization and a discharge ratio which is a function of recurrence interval and impervious cover in the watershed.

Classification: Statistical estimation of peak flow.

Location: Missouri.

36. Golden, H. G. 1977. Preliminary flood-frequency relations for urban streams, metropolitan Atlanta, Ga. U.S. Geolog. Survey (Atlanta, Ga.), Water Resour. Invest. 77-57, 16 pp.

Abstract: A method is presented for estimating the magnitude and frequency of floods for urban streams in metropolitan Atlanta. The effects of urbanization on flood-peak runoff are estimated from a linear and logarithmic form of the multiple regression equation using drainage area, the percentage of drainage basin that is impervious, and the percentage of drainage area served by storm sewers as variables. Equations are presented for estimating the 2-, 5-, 10-, 25-, 50- and 100-year flood peak discharges for basin sizes from 0.5 to 100 square miles in the Atlanta metro area. The 2-year floods computed through the use of this method agree closely with those computed from data collected from 12 urban streams in the Atlanta area. The 100-year flood based on

observed and synthesized data also compares favorably with the 100-year flood computed by using this method. The effect of urbanization on the 100-year flood is less than that on the 2-year flood.

Classification: Statistical estimation of peak flow.

Location: Atlanta, Ga.

37. Haan, C. T. 1975. Comparison of methods for developing urban runoff hydrographs. In National Symposium on Urban Hydrology and Sediment Control, Ky. Univ. (Lexington) Bull. 109, pp. 143-148.

Abstract: The Soil Conservation Service procedures and the Colorado Urban Hydrograph procedure for estimating storm water runoff for urban areas were tested on two urban watersheds in Lexington, Ky. Both procedures gave essentially the same results.

Classification: Single storm event and comparison.

Location: Lexington, Ky.

38. Hall, M. J. 1977. The effect of urbanization on storm runoff from two catchment areas in North London. In Effects of Urbanization and Industrialization on the Hydrological Regime and on Water Quality, IAHS-AISH Publication 123, pp. 144-152.

Abstract: The paper presents deviations of the unit hydrograph parameters from storms recorded on several catchment areas at different stages of urbanization and then correlating these parameters with watershed characteristics which describe the urban area and its growth. The proportion of impervious area main channel length and slope were found to be insufficient to describe urban development.

Classification: Single storm event.

Location: London, England.

39. Hammer, T. R. 1971. Procedures for estimating the hydrologic impact of urbanization. A Report from the Regional Science Research Institute to the Office of Water Resources Research (Washington, D.C.), contract No. C-2174, 33 pp.

Abstract: The major factors determining the hydrologic impact of urbanization may be briefly summarized as follows: (1) The overall intensity of impervious development in the watershed, i.e., the percent of watershed area rendered impervious. (2) The proportion of impervious area which is associated with houses (one- or two-family structures, with driveways, patios, etc.). It was found that the impervious area associated with houses has a much lower hydrologic impact than an equal impervious area of land uses, due presumably to the relatively small size of the individual impervious surfaces in the case

of houses (as opposed to parking lots, factories, etc.). (3) The extent to which streets are provided with storm drainage facilities. It was found that the hydrologic impact of streets is very heavily dependent on the existence of storm sewerage. This is also true for houses; i.e., their effect is dependent upon whether or not they front on sewered streets. (4) The topography of the watershed, including slope and stream-channel slope (which are related in small basins). Various methods of estimating the impervious index are discussed.

Classification: Assessment of data.

Location: Philadelphia, Pa.

40. Hare, G. S. 1970. Effects of urban development on storm runoff rates. In Seminar on Urban Hydrology Proc., U.S. Corps of Engin., Hydrologic Engin. Center, Davis, Calif., 32 pp.

Abstract: A method developed with Donald Vansickle of Turner, Collie, and Braden, Inc., Houston, Tex., by which urban areas in Houston may be analyzed relative to the degree of urbanization of the watershed is discussed. A basin factor equal to the total length of drainage channels times the mean basin length divided by the square root of the mean basin slope was related to the time to peak and the unit hydrograph peak. The total length of channel was determined from drainage density. In the Houston area undeveloped rural areas have drainage densities on the order of 0.8 to 1.0 miles per square mile, while for fully developed storm sewered areas the density is approximately 5.0 miles per square mile.

Classification: Single storm event.

Location: Houston, Tex.

41. Harkins, J. R., and D. A. Olin. 1979. Flood peak discharges of streams in Pleasant Grove, Jefferson County, Alabama. U.S. Geolog. Survey (Tuscalusa, Ala.), Open-file Rpt. 79-252, 11 pp.

Abstract: Estimates of selected peak discharges (recurrence intervals 2-, 10-, 25-, 50-, and 100-year) were made for streams at each road or street crossing and stream confluence in the community of Pleasant Grove, Jefferson County, Ala. Estimates of peak discharge were made for rural, and rural adjusted conditions for effects of urbanization. Equations used to estimate discharges are based on statistical analyses of discharge records for natural streams in Alabama with drainage areas of 1 to 15 square miles. The basin characteristics which are most significant and used in the estimates of discharge are the mean annual natural flood, ratio of mean annual urban flood, and the mean annual natural flood and the rainfall intensity ratio.

Classification: Statistical estimation of peak flow.

Location: Jefferson County, Ala.

42. Harley, B. M. 1978. Research on the effects of urbanization on small stream flow quantity. Federal Highway Administration (Washington, D.C.) Rpt. No. FHWA-RD-78-88, 50 pp.

Abstract: The techniques presented in this report for estimating the magnitude of flood peak discharge are a modification of techniques developed by Anderson. The data base used in this study is essentially the same as used by Anderson in his earlier study. The proposed method has the following form:

$$Q_t = 200 \cdot E \cdot R \cdot A^{0.82} \cdot T^{-0.48} \cdot S_f^{-0.5}$$

where: Q_t = the magnitude of a flood of a flood of t-year recurrence interval in cubic feet per second

$200 \cdot E$ = modification of Anderson's runoff factor of 230 where E is the direct runoff in inches for the 25-year 2-hour duration storm at the basin site for undeveloped conditions

K = coeffiecient of imperviousness as defined by Anderson

R = flood-frequency ration as defined by Anderson

A = basin area in square miles

T = basin lag time as defined by Anderson

S_f = an additional factor which expresses the percentage of drainage basin occupied by lakes or swamps plus 1 percent

In addition, this report provides a way of interpolating between Anderson's curves for lag time on the basis of the percent of the basin which is storm sewered (S_w). The percentage of the basin storm sewered (S_w) is estimated using population density (P) by the following equation:

$$S_w = 0.262 \; P^{0.608}$$

Estimates of flood discharge using the proposed method were made for eight watersheds scattered around the United States and compared with flood discharges estimated for the same watersheds using more detailed simulation models or actual flood peak data.

Classification: Statistical estimation of peak flow.

Location: Entire United States.

43. Harley, B. M., F. E. Perkins, and P. S. Eagleson. 1970. A modular distributed model of catchment dynamics. Mass. Inst. Tech. and Ralph M. Parsons Lab. for Water Resour. and Hydrodynamics (Cambridge, Mass) Rpt. No. 133.

Abstract: The Massachusetts Institute of Technology (MIT) Urban Watershed Model simulates the time-varying runoff of several catchments and a sewer and open channel network including loops and converging and diverging branches. The model is limited to the simulation of single runoff events. Initial losses to fill depression storage on pervious and impervious areas are subtracted before surface runoff begins. There are four options to compute infiltration on the pervious areas: Horton's equation, Holtan's equation,

U. S. Soil Conservation Service method, and a runoff coefficient method. Infiltration is subtracted from rainfall if the last two methods are used, but computed from overland flow depth if Horton's or Holtan's equation is used. The Penman equation is used to compute evaporation but generally not used for single runoff event simulation. Flow routing is accomplished with the kinematic wave equation. The equations are solved by a finite difference scheme for overland flow, flow in gutters, and flow in open channels, and for various standard cross-sections and arbitrary shape closed conduits.

Classification: Single storm event.

Location: Entire United States.

44. Harris. E. E., and S. E. Rantz. 1964. Effects of urban growth on streamflow regimen of Permanente Creek, Santa Clara County, California: Hydrologic effects of urban growth. U.S. Geolog. Survey, (Washington, D.C.), Water Supply Paper 1591-B, 18 pp.

Abstract: This report presents the results of an investigation of the effect of urban growth on the streamflow regimen of Permanente Creek in Mountain View, Santa Clara County, Calif. The data available did not permit a complete study of all hydrologic aspects, but there is conclusive evidence that the volume of storm runoff produced by rainfall on the valley floor has increased substantially as a result of urbanization. In 1945, storm runoff from the 5.12-square mile project area was insufficient to balance channel losses, and the streamflow entering the project area in the Permanente Creek channel was greater than that leaving the area. If, however, total outflow from the project area is considered to be the sum of the streamflow leaving the area plus channel seepage in the area, the ratio of total outflow to inflow was 1.18. By 1958, storm runoff from the project area was far in excess of channel losses and the ratio of total outflow to inflow was 1.70. This increase in outflow is attributed to the fact that urban development during the period 1945 to 1958 increased the extent of impervious surface in the project area from about 4 to 19 percent.

Classification: Assessment of data.

Location: Santa Clara County, Calif.

45. Heeps, D. P., and R. G. Mein. 1974. Independent comparison of three urban runoff models. Amer. Soc. Civil Engin., Jour. Hydraul. Div. 100(HY7): 995-1009.

Abstract: Three urban runoff models (Road Research Laboratory Hydrograph Method, Storm Water Management Model, and Cincinnati Urban Runoff Model) were applied to two urban catchments in Australia. The Road Research Laboratory method generally performed well if runoff from previous areas was insignificant. The Storm Water Management Model was best of the three models but also required the most computer-processor time. The Cincinnati Urban

Runoff Model contained several deficiencies which caused poor performance. Degree of catchment subdivision was found to be an important factor in the magnitude of the peak predicted.

Classification: Single storm event and comparison.

Location: Australia.

46. Henson, W. R. 1970. A unified method for computing peak discharge from ungaged urban areas for corps of engineers studies. In Seminar on Urban Hydrology Proc. U.S. Army Corps of Engin., Hydrologic Engin. Center, Davis, Calif., 15 pp.

Abstract: Three general methods for computing peak discharges from ungaged urban areas for use in Corps of Engineers studies are discussed. These methods include physical models, synthetic unit hydrographs, and comprehensive simulation models. It is felt that physical models would present problems because of the need for different scale parameters where either overland or stream flow dominates. There is also the cost factor since a large investment would be required to build and operate the model and to analyze and present the model results. Henson then discusses the development of methods for computing synthetic unit hydrographs for unit areas and concludes that developing a generalized method for determining the unit hydrograph peaks for ungaged urban areas using one of these methods would require a competent staff, time and sufficient funds to compile the unit hydrographs, basin characteristics, degree of urban development and relating functions. Although this would require a large initial investment, the investment would be offset by ease of use and no recurring cost.

Classification: Single storm event.

Location: Not specified.

47. Hollis, G. E. 1975. The effect of urbanization on floods of different recurrence intervals. Water Resour. Res. 2(3): 431-435.

Abstract: This report summarizes available studies indicating that the urbanization of a watershed can drastically change the flood characteristics of a river. Published results are synthesized to show the general relationship between the increase in flood flows following urbanization and both the percentage of the basin paved and the flood-recurrence interval. Based upon analysis of published data, it appears that (1) floods with a return period of one year or more are not appreciably affected by a 5 percent paving of their catchment area, (2) small floods may be increased by a factor of 10 or more depending upon the degree of urbanization, (3) floods with a return period of 100 years may be doubled in size by the complete urbanization of a catchement if that urbanization results in at least a 30 percent paving of the basin, and (4) the effect of urbanization declines in relative terms as flood-recurrence intervals increase.

Classification: Assessment of data.

Location: Not specified.

48. Horner, W. W., and F. L. Flynt. 1936. Relation between rainfall and runoff from small urban areas. Trans. Amer. Soc. Civil Engin., Paper No. 1926, 66 pp.

Abstract: Rainfall rates and runoff rates at four locations studied are reduced and developed into frequency diagrams. The two sets of curves are considered to be comparable as representing equivalent probabilities of occurrence. Ratios are then developed between corresponding values. Within certain limits, it is suggested that these ratios may be applied to proper rainfall frequency curves for other localities and will give approximate runoff values for similar conditions of surface. Suggestions are offered as to how the values determined might be modified further to be applicable to (a) different surface slopes; (b) other amounts of imperviousness; and (c) other typical soils.

Classification: Statistical estimation of peak flow.

Location: St. Louis, Mo.

49. Hydrocomp Internation, Inc. 1972. Hydrocomp Simulation Programming--Operations Manual. Palo Alto, Calif.

Abstract: The Hydrocomp Simulation Program is one of the most comprehensive mathematical models for the simulation of both rural and urban catchments. The water flow computations are based on the Stanford Watershed Model. The potential infiltration rate is computed from an empirical function of soil moisture. The actual infiltration depends on the rainfall excess after subtracting interception losses rather than on the overland flow depth. The infiltrated moisture is divided into upper zone and lower zone storage. Upper zone storage includes depression storage. Part of the upper zone storage percolates into the lower zone storage and the rest is divided into overland flow and interflow, which become channel (or sewer) inflow. The lower zone storage is divided into a channel inflow contribution and into deep groundwater storage which does not contribute to surface runoff. Interception, upper zone, lower zone, and groundwater storage are depleted by evaporation or evapotranspiration computed as functions of potential evapotranspiration and available moisture. Overland flow is routed with a modified kinematic wave formulation using Manning's equation. Several empirical coefficients relate surface detention storage to overland flow discharge. Flow routing in sewers and open channels is accomplished using the kinematic wave equation with Manning's equation. The solution considers the geometry of circular pipes and of trapezoidal open channels with trapezoidal flood plains. A diffusion term in the kinematic wave equations approximates downstream flow control and backwater conditions. Reservoirs and channels can be simulated in the channel network. Storage capacity has to be defined as a function of depth and reservoir discharge has to be defined by rule curves relating discharge with time.

Classification: Continuous record.

Location: Entire United States.

50. Jackson, T. J., R. M. Ragan, and R. P. Shubinski. 1976. Flood frequency studies on ungaged urban watersheds using remotely sensed data. In National Symposium on Urban Hydrology, Ky. Univ. (Lexington) Bull. 111, pp. 31-39.

Abstract: Regional relationships are presented for predicting the STORM parameters, a runoff coefficient and a depression storage coefficient, from the percent of impervious area. The prediction relationship for the runoff coefficient was developed from an analysis of historical rainfall - runoff data on seven watersheds in the Baltimore-Washington area with percent of impervious areas ranging from 25 to 100 percent. The depression storage coefficient is estimated using 0.25 inch for pervious and 0.06 inch for impervious areas. The regional relationships are evaluated in a study of the Fourmile Run Watershed in northern Virginia. This watershed is gaged, but it was not used in the development of the regional relationships. The flood frequency curve developed using the historic streamflow record is compared with flood frequency curves developed by: (1) a regional flood frequency study conducted by the USGS; (2) STORM calibrated using recent Fourmile Run historic flood data; and (3) STORM with parameters predicted from the Landsat estimated percent of impervious area. The findings indicate that the regional relationships for estimating the STORM coefficients produce results that compare well with those developed through calibration against historic data.

Classification: Continuous record.

Location: Maryland and Virginia.

51. James, L. D. 1965. Using a digital computer to estimate the effects of urban development on flood peaks. Water Resour. Res. 1(2): 223-234.

Abstract: The digital computer program based on water balance methods and known as the Stanford Watershed Model was used to develop a long-term continuous hydrograph (1905-63) for Morrison Creek, Sacramento County, Calif. By varying constants describing the physical conditions within the watershed according to the amount of urban development and channel improvement within the tributary area, a number of continuous hydrographs were developed. A set of curves was developed from these hydrographs that made possible an estimate of flood peak by frequency for any combination of percentage of area urbanized, percentage of channels improved, and tributary area. An analysis was also made of the effects of urban development on runoff volumes and on the distribution of runoff during the year. Seven inputs to the watershed model were altered with the degree of urbanization. The time-area histogram was advanced to reflect the probable installation of storm sewers and more rapid gutter flow. The interception, depression storage, lower and upper zone storages were changed to reflect urbanization. The hydraulic velocities and channel routing coefficient were altered to account for improved channelization.

Classification: Continuous record.

Location: Sacramento County, Calif.

52. James, L. D., and A. M. Lumb. 1975. Flood hydrograph simulation for urban flood frequency analysis: Application to a watershed. In National Symposium on Urban Hydrology and Sediment Control, Ky. Univ. (Lexington) Bull. 109, pp. 169-181.

Abstract: A system of computerized hydrologic simulation for use in analysis of the response of urban streams to the effects of urbanization is described. The systems consisted of (1) the Stanford Watershed Model for simulating runoff volumes and (2) a model that routes the runoff volumes over the land surface and then downstream through channel and storage segments using kinematic routing.

Classification: Continuous record.

Location: DeKalb County, Ga.

53. Jencsok, E. I. 1968. Hydrologic design for highway drainage in Arizona. Ariz. Highway Dept., Bridge Div., 53 pp. Phoenix, Ariz.

Abstract: The publication is a design manual of the Arizona Highway Department for hydrologic design of culverts and bridges. The rational method used in urban areas. The method for rural watersheds uses two different forms depending on whether the area is less or greater than 10 square miles. For areas less than 10 square miles a watershed shape factor is used.

Classification: Statistical estimation of peak flow.

Location: Arizona.

54. Jennings, M. E., and H. C. Mattraw. 1976. Comparison of the predictive accuracy of models of urban flow and water quality processes. In National Symposium on Urban Hydrology Hydraulics and Sediment Control, Ky. Univ. (Lexington) Bull. 111, pp. 1-8.

Abstract: Three models were tested on single event runoff simulation. The models were (1) Stormwater Management Model (SWMM2); (2) ILLUDAS, and (3) MIT Urban Catchment Model. The models tested on four watersheds which were located in Madison, Wis., Jackson, Miss., Pompano, Fla., and Littleton, Colo. All models produced good peak flow predictions.

Classification: Single storm event and comparison.

Location: Colorado, Florida, Mississippi, and Wisconsin.

55. Johnson, K. A. 1970. An analysis of the effects of urbanization on unit hydrograph characteristics, Antelope Creek Basin-Lincoln, Nebr. *In* Seminar on Urban Hydrology, Proc., U.S. Army Corps of Engin. Hydrol. Engin. Center, Davis, Calif., 20 pp.

Abstract: This paper is confined to a discussion of the unit hydrograph analysis made for Antelope Creek. The determination of unit graph characteristics for the urban and rural portions of the basin is presented. Snyder's constants C_t and C_p are determined from the hydrograph of an urbanized portion of the watershed. The parameters used in a logarithmic equation to predict peak discharge were drainage area, percent impervious, time from beginning of runoff to peak of the unit hydrograph, length of the stream, slope of the stream, and Espey's channel factor.

Classification: Single storm event.

Location: Lincoln, Nebr.

56. Johnson, S. L., and D. M. Sayre. 1973. Effects of urbanization on floods in the Houston, Tex., metropolitan area. U.S. Geolog. Survey (Austin, Tex.), Water Resour. Invest. 3-73, 50 pp.

Abstract: This study provides relationships for estimating the magnitudes of annual flood peaks having selected recurrence intervals ranging from 2 to 100 years on streams in the Houston metropolitan area. In the analyses, a 60-year rainfall record was used in a rainfall-runoff model that had been calibrated for each site from a 4- to 10-year period of concurrent rainfall and runoff observations. Flood characteristics for each site were then determined from a frequency analysis of the 60-year synthesized flood record and related by multiple regression to the size of the watershed area and the percentage impervious surface within the watershed. The relations were defined by data from basins having drainage areas ranging from 0.50 to 88.4 square miles and having percentages of impervious areas less than 35 percent. The relations are intended for use in estimating "design values" for channel design. They are not applicable for streams having channel capacities less than the "design values" or for streams partly controlled by flood detention reservoirs. The relationship should apply to coastal areas other than the Houston area, if those areas have similar rainfall-frequency curves, land slopes, and soils.

Classification: Statistical estimation of peak flow.

Location: Houston, Tex.

57. Jones, K. R. 1978. Determination of the effects of urbanization on expected peak flows from small watersheds in DeKalb County, Ga. Unpub. Masters Thesis, Ga. Institute Tech., Atlanta, Ga.

Abstract: This study develops simplified equations that can be used on small watersheds (up to 200 acres) and that can closely approximate the estimated expected peak-flood flows resulting from complete simulation with urban/rural flood-simulation model. Equations were developed in the format

$$Q_x = C_1 A^{C_2} ((1-I)^{C_3}) (\log(1+I))^{C_4} (1+RD)^{C_5} (1+HM)^{C_6}$$

where

Q_x = The magnitude of a flood of x-year recurrence interval in cubic-feet per second; C_1 - C_6 = constants which vary with the value of X; A = drainage area in acres; I = decimal fraction of area impervious; RD = road density in miles per square mile; HM = decimal fraction of channel length hydraulically modified.

Comparisons were made of the results generated from this method with simulations of 30 watershed configurations from the Echo Branch subbasin. There was close agreement between the two results. Results from this study were also compared with results using Leopold's chart, Stankowski's table, and the Sauer-Golden method. None of these were compatible with the equations presented in this study.

Classification: Statistical estimation of peak flow and comparison.

Location: Atlanta, Ga.

58. Jones, S. E. 1970. Tulsa district method of urban hydrology. In Seminar on Urban Hydrology Proc., U.S. Army Corps of Engin. Hydrol. Engin. Center, Davis, Calif., 13 pp.

Abstract: The method used by the Tulsa District Corps of Engineers to determine the effects urbanization has on small areas, with respect to surface runoff, is presented. So far the method has been applied only to synthetic data. Since there are no small drainage areas with stream-flow data available to pattern a study against, no concrete conclusions as to the accuracy of this method were made. The method depends upon an adjustment applied to the Snyder coefficients C_t and C_p used in the derivation of the unit hydrograph. The adjustment is based on the percentage of the watershed storm sewered and the percentage of the natural channel eliminated.

Classification: Single storm event.

Location: Tulsa, Okla.

59. Keiger, C. J., J. P. Harrison, and T. O. Hixson. 1970. Chicago hydrograph method, network analysis of runoff computations. City of Chicago Department of Public Works, Preliminary Report, Chicago, Ill.

Abstract: The Chicago hydrograph method simulates the time-varying runoff in combined sewerage systems consisting of several catchments and converging branch sewer or open channel network. Infiltration losses on pervious areas are computed from Horton's equation which has been modified to account for

actual infiltration. After subtracting infiltration from rainfall, the remaining moisture is reduced by an exponential function of available depression storage and cumulative rainfall excess to account for losses due to depression storage. The remaining moisture then becomes the overland flow contribution from the pervious area. Overland flows from pervious and impervious areas are routed separately by means of a storage routing technique which uses empirical functions and is based on a method by Izzard. The routed overland flows from both pervious and impervious areas are then combined and routed through the gutters by using a storage routing technique. Flow routing is formulated for circular pipes and trapezoidal open channels using a storage routing technique. Manning's equation is solved for the peak flow of each hydrograph to define a linear relationship between storage and discharge.

Classification: Single storm event.

Location: Chicago, Ill.

60. King County Department of Public Works. 1977. Requirements and guidelines for storm drainage control in King County, Seattle, Wash.

Abstract: A design manual for King County, Washington, for hydrologic design of storm drainage facilities. The rational formula is used to determine peak flow.

Classification: Statistical estimation of peak flow.

Location: King County, Wash.

61. Laenen, A. 1980. Magnitude and frequency of storm runoff as related to urbanization in the Portland, Oregon-Vancouver, Washington area. U.S. Geolog. Survey (Portland Wash.), Open File Report.

Abstract: A series of equations was developed to provide a better method of determining flood frequencies in the Portland-Vancouver urban area than is now available. Those physical basin parameters that proved to be significant are: drainage area, effective impervious area, storage, rainfall intensity, basin slope, and soil infiltration. The equations indicate that there is a fourfold increase in peak flow and a twofold increase in total runoff from undeveloped to fully developed urban basins. Impervious area, as delineated by mapping techniques, proved to be an inadequate physical parameter for use in the regression equations. The resulting regression equations can be used to compute peak discharge and storm runoff to an accuracy of approximately 30 percent, on the average.

Classification: Statistical estimation of peak flow.

Location: Portland, Oreg. and Vancouver, Wash.

62. Lanyon, R. F., and J. Jackson. 1974. Flow simulation system. Amer. Soc. Civil Engin., Jour. Hydraul. Div. 100(HY8): 1089-1105.

Abstract: The Chicago flow simulation program is intended primarily for the simulation of large catchments consisting of both sewered and nonsewered areas. It simulates the time-varying runoff in combined sewerage systems and nonurban drainage basins consisting of several catchments and a converging branch sewer and open channel network. The flow routing formulation for natural channels includes provisions for flow and storage in flood plains. The model can be used for continuous simulation using hourly or shorter time steps. Different formulations are used for the computation of runoff from rainfall for sewered and nonsewered areas. If the area is sewered, it is assumed that the rainfall-runoff relationship is linear and that the water stored on the catchment during a time step flows into the sewer during the same time step. It is assumed that all rain falling on impervious areas becomes runoff and a constant fraction of the rain falling on pervious areas becomes runoff. For nonsewered areas, it is assumed that all rain falling on impervious areas becomes runoff. A time delay is introduced, however, by specifying that a constant fraction of the water stored on the impervious areas becomes runoff during each time step. This again neglects the effect of variations in catchment shape, slope, and surface roughness on overland flow. For pervious areas, rainfall losses are computed by using an empirical function relating the losses to rainfall, catchment shape, and soil moisture. Continuous accounting of soil moisture is accomplished with an empirical equation which considers deep percolation and evaporation. Evaporation is defined as a function of soil moisture at each time step and average daily air temperature. Linear storage routing is used to compute overland flow from the pervious areas, considering overland flow storage, catchment shape and slope but assuming a constant surface roughness. Flow routing in both circular sewers and trapezoidal open channels is accomplished by a storage routing technique using Manning's equation.

Classification: Single storm event.

Location: Not specified:

63. Lara, O. G. 1978. Effects of urban development on the flood - flow characteristics of the Walnut Creek Basin, Des Moines Metropolitan area, Iowa. U.S. Geolog. Survey (Iowa City, Iowa), Water Resour. Invest. 78-11, 31 pp.

Abstract: This report deals with the probable impact of urban development on the magnitude and frequency of flooding in the lower reach of the Walnut Creek Basin. Stream-modeling techniques, which include complete definition of unit hydrographs and precipitation loss-rate criteria, were utilized to evaluate the effects of urban development as measured by percentages of impervious area over the basin. HEC-1 was calibrated by using the concurrent rainfall-runoff data collected at three gaging stations in the basin. The model parameters were regionalized to allow future users to estimate the model parameters for ungaged areas within the basin. Long-term rainfall data recorded at two nearby stations were employed as basic input to the calibrated model to generate annual peak discharges corresponding to selected degrees of

urbanization. Results are presented in tables and graphs, which compare the pre-urban and urban flood flow characteristics of the lower reach of the Walnut Creek Basin.

Classification: Single storm event.

Location: Des Moines, Iowa.

64. Leopold, L. B. 1968. Hydrology for urban land planning--a guidebook on the hydrologic effects of urban land use. U.S. Geolog. Survey (Arlington, Va.), Cir. 554, 18 pp.

Abstract: Existing knowledge of the effects of urbanization on hydrologic factors is summarized. The effects of urbanization as determined by seven investigators are summarized and the results used to develop a relationship showing the effect of urbanization on the mean-annual flood for a 1 square-mile drainage area. The parameters used to describe urban development in the relationship were the percentage of the area served by storm sewers and the percentage of the area that was impervious.

Classification: Statistical estimation of peak flow.

Location: Pennsylvania.

65. Liscum, F., and B. C. Massey. 1980. Techniques for estimating the magnitude and frequency of floods in the Houston, Texas, metropolitan area. U.S. Geolog. Survey (Austin, Tex.), Water Resour. Invest. 80-17.

Abstract: The equations provided in this report for estimating the magnitude and frequency of flood discharges are an update of Johnson and Sayre's 1973 equation. A regression model, relating flood-peak discharge to concurrent rainfall and antecedent soil moisture conditions, was used to simulate 67 years of annual peak discharges at each site using long-term rainfall data in Houston. Flood-frequency characteristics were determined for the simulated and observed annual peak records at each of 22 sites. The two sets of flood-frequency discharges were weighted and used in a multiple regression analysis with watershed characteristics. Equations relating drainage area, bank-full channel conveyance, and percentage of urban development were computed. The percentage of urban development was defined as the percentage of the total contributing drainage area within 200 feet of streets, roads, parking lots, and industrial sites that are drained by open street ditches or storm sewers. The watersheds used to develop these equations ranged from 1.33 to 182 square miles with the percentage of urban development varying from 37 to 98.9 percent and bank-full channel conveyance ranging from 12,000 to 2,800,000 cubic feet per second. These relationships which are applicable for unregulated streams had standard errors of estimate of 17 to 25 percent depending on the return period of the design discharge.

Classification: Statistical estimation of peak flow.

Location: Houston, Tex.

66. Lopez, N. C., and G. L. Dugan. 1975. Estimating peak discharges in urbanizing Hawaiian watersheds for selected rainfall frequencies. In Hydraulic Engineering for Optimal Use of Water Resources, 23d Ann. Speciality Conf., Seattle, Wash.

Abstract: Modification of the Soil Conservation Service method which may be used to study the effect of urbanization and other land use changes on peak discharge in Hawaii is presented. A unique time of concentration formula design for Hawaii was used. Also, watersheds were segregated into response zones according to slope. The input data included soil class, soil cover, hydraulic length, and average slope. Urbanization is accounted for in the curve number.

Classification: Single storm event.

Location: Hawaii.

67. Los Angeles County Flood Control District. 1971. Hydrology manual: Sections A through E, Los Angeles County Flood District, Hydraulic Division, Los Angeles, Calif., 238 pp.

Abstract: Flood estimates are made by using a modification of the rational method, with time-area routing to produce a composite storm hydrograph from all subareas. The runoff coefficient varies with rainfall intensity and urban development. An extensive series of design charts are presented.

Classifiction: Statistical estimation of peak flow.

Location: Los Angeles, Calif.

68. Lumb, A. M., and L. D. James. 1975. Flood hydrograph simulation for urban flood frequency analysis: The model. In National Symposium on Urban Hydrology and Sediment Control, Ky. Univ. (Lexington) Bull. 111, pp. 169-179.

Abstract: The Stanford watershed model is used to generate a runoff file, and a program developed to route that runoff from an urban watershed, which may be subdivided into subareas and channel and storage segments. This model is used to simulate an annual series of flood peaks and perform a flood frequency analysis at a selected point.

Classification: Continuous record.

Location: Georgia.

69. McPherson, M. B. 1969. Some notes on the rational method of storm drain design. Amer. Soc. Civil Engin. (New York, N.Y.), Tech. Memo. No. 6, 74 pp.

Abstract: The procedure used for design of storm sewers in the United States is almost exclusively the "rational method." Three factors affect the

magnitude of a design flow in using the rational method: C-value, inlet time and the frequency for the rainfall intensity-duration curve used. Computed flows are larger as the C-value is raised, as the inlet time is shortened, and as a curve for a rarer rainfall frequency is used. Intelligent, though arbitrary, selection of values for these three variables has been found to give ostensibly "satisfactory" results in a number of cities.

Classification: Statistical estimation of peak flow.

Location: Entire United States.

70. Marsalek, J., T. M. Dick, P. E. Wisner, and W. G. Clarke. 1975. Comparative evaluation of three urban runoff models. Water Resour. Bull. 11(2): 306-329.

Abstract: Three urban runoff models, namely, the Road Research Laboratory Model (RRLM), the Storm Water Management Model (SWMM), and the University of Cincinnati Urban Runoff Model (UCURM), were examined by comparing the model simulated hydrographs with the hydrographs measured on several instrumented urban watersheds. This comparison was done for the hydrograph peak points as well as for the entire hydrographs using such statistical measures as the correlation coefficient, the special correlation coefficient and the integral square error. The study indicated that, when applying the three selected noncalibrated models on small urban catchments, the SWM model performed marginally better than the RRL model and both these models were more accurate than the UCUR model.

Classification: Single storm event and comparison.

Location: Canada, and Chicago, Ill.

71. Martens, L. A. 1968. Flood inundation and effects of urbanization in metropolitan Charlotte, N.C. U.S. Geolog. Survey (Arlington, Va.), Water-Supply Paper 1591-C, 59 pp.

Abstract: The effect of urban development on floods in Charlotte was determined by comparing mean annual flood data from 6 urban sites with similar data from 31 nearby rural sites. Carter's (1961) methods and flood formulas were used. Drainage area of the urban sites ranged from 6.98 to 41.0 square miles and impervious areas ranged from 2.1 to 22.3 percent. The logarithmic relationship used the ratio to mean annual flood as determined from a graph showing variation of flood-frequency ratio with percent of impervious cover (I) and drainage area and lag time as determined from a graph showing effect of urban development on lag times. Lag time used stream length and channel slope as parameters.

Classification: Statistical estimation of peak flow.

Location: Charlotte, N. C.

72. Matthias, C. D. 1970. Urban hydrology in connection with channel improvement project at New Market Creek, Virginia. In Seminar on Urban Hydrology Proc. U.S. Army Corps of Engin., Hydrologic Engin. Center, Davis, Calif., 14 pp.

Abstract: Procedures are discussed to provide hydrologic data necessary to design a channel improvement project at New Market Creek, Va. Unit hydrographs were derived for a number of different times of concentration. The 2-, 10-, and the 100-year flood discharges were then obtained by application of appropriate storm rainfall to the unit hydrographs. It was assumed that for a given time of concentration, the peak flood discharge and the peak of the unit hydrograph are directly proportional to the drainage area. Curves were developed for present and developed conditions using different rates of rainfall losses.

Classification: Single storm event.

Location: New Market, Va.

73. Metcalf & Eddy, Inc., University of Florida, and Water Resources Engineers, Inc. 1971. Storm water management model. U.S. Environ. Protect. Agency (Washington, D.C.) Rpt. 11024 DOC 07/71.

Abstract: The U.S. Environmental Protection Agency's Stormwater Management Model is a comprehensive mathematical model for the simulation of storm and combined sewerage systems. The combined storm and sanitary runoff are computed from several catchments and the flows are routed through a converging branch sewer network. Losses are subtracted separately from the rainfall on pervious and impervious areas. Runoff occurs only when all depression storage is filled. No other losses are computed for impervious areas. Evaporative losses are not computed. For pervious areas, the potential infiltration is computed with Horton's equation and the actual infiltration depends on the available overland flow depth. Overland flow is computed separately for pervious and impervious areas by using a kinematic wave formulation with Mannings' equation. A similar formulation is used for the gutter flow routing. Flow routing in the sewers is accomplished with the kinematic wave equation using Manning's equation. The watershed being modeled is conceptually represented by a network of hydraulic elements (i.e., catchments, gutters, and pipes). A catchment is envisioned as a unit of uniform watershed characteristics, such as surface cover and ground slope. Each catchment is defined by area, width, ground slope, the detention depth requirements, the roughness factor (such as Manning's coefficient), and the coefficients describing the infiltration loss by Horton's equation. Gutters and pipes are characterized by the Manning's coefficient, length, invert slope, and geometric description of the network.

Classification: Single storm event.

Location: Entire United States.

74. Miller, C. R., and W. Viessman. 1972. Runoff volumes from small urban watersheds. Water Resour. Res. 8(2): 429-434.

Abstract: An empirical equation estimates the runoff volume from rainfall on small urban watersheds. If the rainfall is less than 1.5 inches, the runoff is predicted by the relationship between the percent impervious area in the watershed and the percent excess rainfall. An adjustment is made for the initial abstraction combined with the initial surface depression storage. For rainfall amounts greater than 1.5 inches, an additional increment of runoff is added for the pervious areas by using the hydrologic soil class, the vegetative cover, and the controlling parameters. Detailed 1- or 5-minute rainfall and runoff records from 4 small urban watersheds for 77 storms were used to develop the procedure. The method was tested on 17 additional storms on these watersheds. The maximum prediction error was 37 percent for over 80 percent of the test events. The median error was 17 percent of the actual runoff. Linear rainfall-runoff relationships were developed for each watershed. Standard errors of estimate ranged from 10 to 28 percent. The predicted rainfall for zero runoff varied from 0.07 to 0.18 inch.

Classification: Statistical estimation of peak flow.

Location: Chicago and Champaign-Urbana, Ill., and Baltimore, Md.

75. Mills, W. C., W. M. Snyder, T. K. Woody, R. B. Slack, and J. D. Dean. 1976. Use of a piecewise linear model with spatial structure and input for evaluating agricultural to urban hydrologic impact. In National Symposium on Urban Hydrology, Hydraulics, and Sediment Control, Ky. Univ. (Lexington) Bull. 11, pp. 191-193.

Abstract: A distributed watershed model that provides a framework for evaluating the hydrologic impact of change from agricultural to urban land use is described. The model incorporates a grid system for obtaining and structuring input of spatially distributed watershed and rainfall information. The Soil Conservation Service curve number system is used to quantify watershed soil-cover complexes and is linked to a retention function for determining effective rain and runoff. Routing of overland and channel flow is done by convolution with the impulse response of a linear reservoir. The reservoir time constant is related to Manning's flow equation and a feedback mechanism is incorporated to give piecewise linearization of the watershed response. The watershed model is tested on three instrumented watersheds by simulating runoff hydrographs and comparing them with measured hydrographs. Use of the model for evaluating hydrologic effects of urbanization is demonstrated by simulating and comparing hydrographs for several different land-use patterns.

Classification: Single storm event.

Location: Ahoskie, N. C.; Coshocton, Ohio; and Fennimore, Wis.

76. Minneapolis-St. Paul Sanitary District. 1971. Dispatchng system for control of combined sewer losses. U.S. Environ. Protect. Agency (Washington, D.C.) Rpt. 11020 FAQ 03/71.

Abstract: The Minneapolis-Saint Paul Urban Runoff Model was developed for realtime forecasting of flows in the major trunk and interceptor sewers of the Minneapolis-Saint Paul combined sewerage system. The rainfall excess contribution of each catchment is computed separately for pervious and impervious areas. Runoff does not begin until all depression storage is filled. Other losses are computed for impervious areas by an exponential function and by a modified Holtan's equation for pervious areas. The excess precipitation is then convoluted with unit hydrographs to determine the storm runoff from each catchment. The unit hydrographs are computed from catchment characteristics such as drainage area, length, slope, soil, and vegetation by the Soil Conservation Service method. The same unit hydrograph is applied to runoff from both the pervious and impervious portion of each catchment. The progressive average lag method is used to route the flows in the sewers. The method requires two empirical coefficients (an average travel time and the number of upstream flow values to be averaged to obtain a downstream routed flow value) which must be obtained by calibration with measured data or by derivation with a different routing method.

Classification: Single storm event.

Location: St. Paul, Minn.

77. Narayana, V. V. D., M. A. Sial, J. P. Riley, and E. K. Israelsen. 1970. Statistical relationships between storm and urban watershed characteristics. Utah State Univ. (Logan), Utah Water Res. Lab. No. PRWG 74-2, 55 pp.

Abstract: Equations for predicting peak runoff rates and maximum runoff volumes from small urban and rural watersheds that are based on measurable storm and watershed characteristics are provided. The technique was tested for runoff events for both urban and rural watersheds. The parameters used in developing the peak flow equations were area, slope, main channel length, storm duration, total rainfall, maximum 30-minute rainfall, impervious cover factor, and degree of channelization. The three models developed were (1) a multiple linear regression, (2) a regression with the independent variables raised to a power, and (3) the independent variables grouped to form three independent factors and then used to form a regression equation with the independent parameters raised to a power. The three independent factors were (1) watershed factor which is a function of area and channel length; (2) storm factor which is a function of storm duration and total 30 minute rainfall; and (3) urbanization factor which is a function of channelization and impervious cover factor. The 20 urban watersheds used were in Texas and Maryland and accounted for 193 of the 393 storms used in the analysis. For the urban areas correlation coefficient of between 0.8 and 0.9 were obtained.

Classification: Statistical estimation of peak flow.

Location: Maryland and Texas.

78. National Water and Soil Conservtion Organization. 1975. Metric version of technical memorandum number 61, 19 pp. Wellington North, New Zealand.

Abstract: An empirical method for estimating a design flood peak discharge in an ungaged New Zealand watershed the equation is:

$$Q_p = 0.0139\ C\ R\ S\ A^{3/4}$$

where Q_p = estimate of the design peak discharge, in m^3/s
C = a coefficient which depends on the physiography of the catchment
R = a rainfall factor which depends on the design storm
S = a catchment shape factor
A = catchment area, in km^2.

The effect of urbanization is described in the C parameter based on density of development and the infiltration characteristics of the soil. Three types of concentration methods are described and used in the method.

Classification: Statistical estimation of peak flow.

Location: New Zealand.

79. Nelson, T. 1970. Synthetic unit hydrograph relationships, Trinity River Tributaries, Fort Worth-Dallas urban area. In Urban Hydrology Seminar Proc., U.S. Army Corps of Engin., Hydrol. Engin. Center, Davis, Calif., 18 pp.

Abstract: Relationships are presented to develop synthetic unit hydrographs for ungaged areas in the Fort Worth-Dallas area. For different degrees of urbanization, curves are presented which can be used to determine the lagtime (time to peak). The curves indicate that in the Fort Worth-Dallas area a complete change from a rural to a fully developed urban condition would reduce the lag for a watershed by about 50 percent, and the peak discharge of the unit hydrograph would be approximately doubled.

Classification: Single storm event.

Location: Dallas-Fort Worth, Tex.

80. New Zealand Institution of Engineers. 1979. A guideline and procedure for hydrological design of urban storm water systems. New Zeal. Inst. Engin. (Auckland), 25 pp.

Abstract: Urban design manual for New Zealand. The rational formula is used to determine peak flows. A very detailed method of determining time of concentration is presented.

Classification: Statistical estimation of peak flow.

Location: New Zealand.

81. Offner, F. F. 1973. Computer simulation of storm water runoff. Amer. Soc. Civil Engin., Jour. of the Hydraul. Div. 99(HY12): 2185-2194.

Abstract: A computer program has been developed that gives an approximate solution of the partial differential flow equation over the area. The area considered is divided into a grid of squares, with the elevation and soil condition (flow coefficient, initial surface retention, and infiltration rate) tabulated for each grid element. Typical rainfall data are entered, and the program gives the runoff into drainage lines as a function of time.

Classification: Single storm event.

Location: Not specified.

82. Overton, D. E., W. L. Troxler, and J. Bales. 1978. A manual for simulating design hydrographs in urban regions using kinematic wave theory and SCS curve numbers. Environmental Planning Engineers, Inc., 166 pp. Knoxville, Tenn.

Abstract: The urban peak runoff design method utilized kinematic wave theory and Soil Conservation Service curve numbers. The kinematic approximation yields a solution for time of concentration as a function of the roughness, length and slope of the catchment, and the generating rainfall excess intensity. For small watersheds, a graphic solution is presented for peak runoff rate at equilibrium for return periods of 2 to 100 years as functions of (1) frequency of generating intensity, (2) physical characteristics of the basin, and (3) soil type and land use. Also, time of concentration and peak flow are plotted for each return period for each metropolitan area as a function of SCS-Curve Number and the catchment or watershed lag modulus. Methods for simulating lag modulus as a function of basin roughness and geometry are also included. A simplified formula for determining the lag modulus took the form:

$$\text{lag modulus (hours)} = 3.24 \left(\frac{\text{area}}{\text{\% impervious area}} \right)^{0.6}.$$

Classification: Single storm event.

Locations: Birmingham and Mobile, Ala.; Phoenix, Ariz.; Los Angeles and San Diego, Calif.; Denver, Colo.; Miami, Fla,; Atlanta, Ga.; Chicago, Ill.; Indiannapolis, Ind.; Kansas City, Kan.; Louisville, Ky.; New Orleans, La.; Boston, Mass.; Detroit, Mich.; Minneapolis, Minn.; St. Louis, Mo.; Las Vegas, Nev.; Buffalo and New York, N.Y.; Cinncinnati and Cleveland, Ohio; Tulsa, Okla.; Portland, Oreg.; Philadelphia and Pittsburgh, Pa.; Nashville, Tenn.; Dallas, Fort Worth, El Paso, and Houston, Tex.; Salt Lake City, Utah; Seattle, Washington; Washington, D.C.; and Milwaukee, Wis.

83. Packman, J. C., P. P. Lynn, M. A. Beran, M. J. Lowing, and C. H. R. Kidd. 1976. The effect of urbanization on flood estimates. Inst. Hydrol. (Wallingford, England), Urban Drainage Res. Note to the Natl. Water Council, WP-HDSS-76117,12 pp.

Abstract: An equation to predict the time to peak for urban unit hydrograph based on watershed characteristics of main stream length, slope of main stream between 10 and 85 percent of the length, and percent imperviousness. The amount of urban runoff was derived from a regression equation using the rural runoff, a soil index and the amount of imperviousness. The mean annual urban flood was determined by multiplying the rural mean annual flood by a factor based on the percent imperviousness. Graphs of the effect of urbanization on mean annual flood and on growth curves are presented. The only parameter showing any apparent variation with urbanization was that governing the rate of change in the curvature of the growth curves. The variation indicated a flattening of the urban growth curve for less frequent floods. The T year urban flood is derived using the mean annual urban flood and the growth curves.

Classification: Statistical estimation of peak flow.

Location: England.

84. Papadakis, C., and H. C. Preul. 1972. University of Cincinnati Urban Runoff Model. Amer. Soc. Civil Engin., Jour. Hydraul. Div. 98(HY10): 1789-1804.

Abstract: The University of Cincinnati Urban Runoff Model simulates the time-varying runoff of storm sewerage systems consisting of several catchments and a converging branch sewer and open-channel network. Losses to depression storage for both pervious and impervious areas are subtracted as a function of available depression storage capacity and cumulative rainfall and losses. Infiltration on pervious areas is computed with Horton's equation, with its time origin offset to balance cumulative rainfall and potential infiltration. Overland flow is computed by a storage routing technique using Manning's equation and includes several empirical coefficients to relate surface detention storage with overland flow. The gutter flow routing uses a steady state approach, assuming that the gutter outflow equals its inflow during the same time interval. Flow routing in the sewers is accomplished by a simple translation of the upstream hydrograph by its average travel time computed with Manning's equation.

Classification: Single storm event.

Location: Entire United States.

85. Papadakis, C. N., and H. C. Preul. 1973. Testing methods for determination of urban runoff. Amer. Soc. Civil Engin., Jour. Hydraul. Div. 99(HY9): 1319-1335.

Abstract: A brief outline of various methods developed for the calculation of urban stormwater runoff is presented. The Chicago Method, the Road Research Laboratory Method, the Environmental Protection Agency (EPA) Storm Water Management Model, and the University of Cincinnati Urban Runoff Model were tested in three urban watersheds: Chicago 10-acre tract, Oakdale 12.9-acre drainage area, and Bloody Run 1,280-acre urban watershed. All four methods successfully simulate storm water runoff hydrographs in the case of the two

small drainage areas. Runoff hydrographs obtained from EPA Stormwater Management Model and the University of Cincinnati Urban Runoff Model are compared with recorded hydrographs at the outlet of the Bloody Run Sewer Watershed at Cincinnati, Ohio. The comparisons indicate that the estimation of the infiltration capacity to be used in these models is of predominant importance in the case of large urban drainage areas.

Classification: Single storm event and comparison.

Location: Chicago and Oakdale, Ill., Cincinnati, Ohio.

86. Peek, C. D., and P. R. Jordan. 1978. Determination of peak discharge from rainfall data for urbanized basins, Wichita, Kans. U.S. Geolog. Survey (Wichita, Kans.), Open-file Rpt. 78-974, 49 pp.

Abstract: Rainfall and runoff data from urbanized drainage basins in Wichita Kans., were used to evaluate the Soil Conservation Service synthetic-hydrograph method of computing flood hydrographs from rainfall data. The method was tested on six basins. After modification of the method, results showed an average error of 20 percent, and an apparent bias of 8 percent. However, uncertainties in some of the data make adjustment for bias impractical.

Classification: Single storm event.

Location: Wichita, Kans.

87. Putnam, A. L. 1972. Effect of urban development on floods in the Piedmont province of North Carolina. U.S. Geolog. Survey (Raleigh, N.C.), Open-file Rpt., 87 pp.

Abstract: This report relates peak discharges for recurrence intervals ranging from 1 to 100 years to drainage area, stream length, stream slope, and percent of basin covered by impervious surfaces. The relations are based on analysis of flood information for approximately 200 sites, 42 of which are in metropolitan areas of the North Carolina Piedmont province. Drainage areas ranged from 0.27 to 178 square miles and impervious cover ranged from less than 1 to 32 percent. The estimating relations are limited to providing flood discharge estimates at open-channel sites in the Piedmont province of North Carolina where runoff is unaffected by artificial storage or diversion. The estimates are most reliable for smaller size floods at sites where the drainage area ranges between 0.3 and 150 square miles, where the L $\sqrt{s}$ ratio ranges between 0.1 and 9.0, and where impervious cover of less than 30 percent is uniformly distributed over the basin. The analysis was divided into two parts: (1) an equation developed for predicting the effect of urban development on the basin lag time and (2) equations developed for predicting flood-peak discharge for recurrence intervals ranging from 1 to 100 years. In both parts of the data analysis, multiple regression techniques were used in the development of the equations. The lag time equation, which has a standard error of estimate of ± 20 percent, used length of the main water course, slope of the main water course, and ratio of the area of impervious cover to the

total drainage area. The flood-frequency equations, which have standard errors of estimate of ±30 percent for the 2- to 10-year events and ±35 percent for the 25-year event, used lag time and drainage area as parameters in a logarithmic relationship.

Classification: Statistical estimation of peak flow.

Location: North Carolina.

88. Ragan, R. M., M. J. Root, and J. F. Miller. 1975. Dimensionless inlet hydrograph model. Amer. Soc. Civil Engin., Jour. Hydraul. Div., 101(HY9): 1185-1195.

Abstract: The dimensionless hydrograph model is a linked system that uses a hyetograph in the form of a series of step functions as rainfall input, infiltration depression storage, and rainfall excess are computed using the technique used in the Chicago Hydrograph Model and the overland flow uses the Overton modified kinematic wave theory. The watershed characteristics used are length and width of the watershed, area, slope, and percent imperviousness. Method gives the hydrograph.

Classification: Single storm event.

Location: Maryland.

89. Rao, R. A., and J. W. Delleur. 1974. Instantaneous unit hydrographs, peak discharges and lags in urban basins. Hydrol. Sci. Bull.-des Sci. Hydrolog. 19(2): 185-198.

Abstract: An example of the possible difficulties that might be encountered in the analysis of urban hydrological data by the unit hydrograph method is presented. The disadvantages of relating the peak discharge, the time to peak discharge, and the time lag to the physiograph characteristics alone were also discussed. Alternative regression relationships that involve storm characteristics along with the physiographic characteristics to estimate the peak discharge, time to peak discharge, and time lag were presented. The variables used in the regression analysis were the fraction of the impervious area, the magnitude of the effective precipitation, the duration of the effective precipitation, and the area of the watershed. The equation of the independent variables were raised to a power.

Classification: Statistical estimation of peak flow.

Location: Not specified.

90. Rao, R. A., J. W. Delleur, and B. S. P. Sarma. 1977. Conceptual hydrologic models for urbanizing basins. Amer. Soc. Civil Engin., Jour., Hydraul. Div., 98(HY7): 1205-1220.

Abstract: After a preliminary analysis of several conceptual models, the single linear reservoir and the Nash model were selected for further study. Analysis of about 200 storms from watersheds with different degrees of development indicated that the parameters of the aforementioned two models varied not only with the urbanization factor (related to the ratio of the built-up area in a watershed to the total watershed area) but also with other physiographical and meteorological factors. Regression relationships between the parameters of the models and the more significant meteorological and physiographical factors including the urbanization factor were developed. These regression relationships were used to simulate the instantaneous unit hydrographs on a watershed with increasing urbanization factors. Changes in runoff from a watershed with increasing urbanization factors were then simulated for a variety of rainfall characteristics.

Classification: Statistical estimation of peak flow.

Location: Not specified.

91. Ray. D. L. 1973. Simulation of control alternatives for combined sewer overflows. Mass. Univ., (Amherst), Dept. Civil Engin., Rpt. No. EVE 33-73-4.

Abstract: The University of Massachusetts combined sewer control simulation model simulates the time-varying runoff of several catchments and a single string of circular sewers. The model computes surface runoff from impervious areas only using hourly rainfall data which may be computed by a separate Markov chain model. The flow routing is accomplished with an implicit solution of the dynamic wave equations which consider upstream and downstream flow control, backwater, and flow reversal.

Classification: Single storm event.

Location: Massachusetts.

92. Riley, P. J., and V. V. D. Narayana. 1968. Modeling the runoff characteristics of an urban watershed by means of an analog computer, effects of watershed changes on streamflow. In Water Resources Symposium Number Two, Tex. Univ. (Austin), Center for Res. in Water Resour., pp. 183-200.

Abstract: A method of urban watershed modeling with the use of an analog computer is presented. The urban parameters considered are percentage impervious cover and the characteristic impervious length factor. The urban watershed is transformed into a hypothetical equivalent rural watershed which possesses uniform physical characteristics. A mathematical model for this equivalent watershed is developed with precipitation as input. The mathematical model is capable of abstracting losses due to interception, infiltration, and depression storage, and of routing the rainfall excess through overland and channel flow storages. This mathematical procedure is programmed on an analog computer and is tested with data from the Waller Creek

watershed at Austin, Tex., for the period 1956-65. Forty-eight storm events were simulated on the analog computer and the simulated outflow hydrographs were verified with observed data.

Classification: Continuous record.

Location: Austin, Tex.

93. Robey, D. 1970. Effects of urbanization on annual peak flow frequency analysis. In Seminar on Urban Hydrology, Proc., U.S. Army Corps Engin., Hydrol. Engin. Center, Davis, Calif., 14 pp.

Abstract: Relationships for estimating the magnitude and frequency of occurrence of flood peaks on a drainage basin having a high degree of urban development are examined. Five different approaches are used to calculate peak discharges. These included procedures as recommended by Beard, both with and without a high outlier, the adjustment of the historical record according to the ratio of the mean annual flood from computed present conditions vs. those for 1951-55 and 1956-60, and finally the use of the following equation, plus the development of frequency curves using the Log-Pearson Type III distribution. The last method was selected for adoption for Four-Mile Run Basin, Va., and lag time was related to stream length and basin slope. The mean annual flood is related to drainage area, lag time and a coefficient of imperviousness (1.0 + 0.015 percent imperviousness).

Classification: Statistical estimation of peak flow.

Location: Alexandria, Va.

94. Rovey, E. W., and D. A. Woolhiser. 1977. Urban storm runoff model. American Soc. Civil Engin., Jour. Hydraul. Div. 103(HY11): 1339-1351.

Abstract: A surface flow routing model based upon a kinematic cascade of planes and channels is combined with a parametric infiltration model to constitute a watershed model. The kinematic approximation is used to route flows through storm drains of trapezoidal or circular cross section. Model parameters are estimated from the hydraulic characteristics of the surface and soils. A Chezy friction relationship is used to model surface flow resistance. The predictive ability of the watershed model is tested by simulating runoff hydrographs from a 67-ha urban watershed near Denver, Colo.

Classification: Single storm event.

Location: Denver, Colo.

95. Russel, S. O., B. F. I. Kenning, and G. L. Greg. 1979. Estimating design flows for urban drainage. Amer. Soc. Civil Engin., Jour. Hydraul. Div. 105(HY1): 43-52.

Abstract: A method for computing design flows and storage volumes was developed for a municipality near Vancouver in western Canada. Parameters can be specified either with single values or by ranges, taking into account parameter uncertainty. The Clark model in which rainfall is logged by a time-area curve and routed through linear storage was used in conjunction with HEC-1 as the hydrologic model. Methods for estimating the infiltration rate, time of concentration, and the storage constant were given with the storage constant being related to the time of concentration and cover type. The infiltration index was based on soils and time of concentration was calculated in the traditional way.

Classification: Single storm event.

Location: Western Canada.

96. Saah, A. D., and E. Watson. 1976. Santa Clara Valley Water District urban hydrology - use of the Corps of Engineers flood hydrograph package HEC-1 as a predictive model. In National Symposium on Urban Hydrology, Hydraulics, and Sediment Control, Ky. Univ. (Lexington) Bull. 111, pp. 203-214.

Abstract: A model is described that accounts for the effects on runoff due to two major urban changes, increased imperviousness and channelization. The existing HEC-1 computer program developed by the Corps of Engineers Hydrologic Engineering Center is used. A concept of subdividing an urban area into hydrologically equivalent pervious and impervious elements are used. For each of these elements, synthetic unit hydrograph parameters were calculated separately. Inflow hydrographs at storm drain system inlets were obtained. Also, storage-discharge relationships determined from storm drains, manholes, gutters, and streets are used. This storage-discharge relationship is regional in nature and applicable to urban areas of the type found in San Jose for the purpose of flood routing.

Classification: Single storm event.

Location: San Jose, Calif.

97. Sarma, P. B. S., J. W. Delleur, and A. R. Rao. 1979. A program in urban hydrology: Part II, an evaluation of rainfall-runoff models for small urbanized watersheds and the effect of urbanization on runoff. Purdue Univ. (Lafayette, Ind.), Water Resour. Res. Center, 240 pp.

Abstract: The analysis of data from watersheds that are in the same region but in different stages of urbanization reveals the effects of urbanization on runoff characteristics. This comparison of analyses was the general approach used in the study. The following conceptual linear systems were used in the analysis of the data: The single linear reservoir model, the double routing method, the Nash model, the single linear-reservoir with linear-channel model. The effects of urbanization on the time lag, the magnitude of the peak discharge, the time to peak discharge, and on the frequency of peak discharge were quantitatively deduced. Tentative relationships were developed to

predict changes in the time distribution of runoff, in the peak discharge, in the time to peak discharge, and in the frequency of peak discharge for watersheds which are urbanized to different degrees.

Classification: Single storm event.

Location: Indiana and Texas.

98. Sauer, V. B. 1974. An approach to estimating flood frequency for urban areas in Oklahoma. U.S. Geolog. Survey (Oklahoma City, Okla.), Water Resour. Invest. 23-74, 10 pp.

Abstract: Flood-frequency studies for urban areas in several parts of the United States and flood-frequency relations for natural streams of Oklahoma were used to develop a set of flood-frequency equations for urban areas of Oklahoma. Equations are presented for estimating the 2-, 5-, 10-, 25-, 50-, and 100-year flood-peak discharges for basins 0.5 to 100 mi^2 (1.3 to 260 km^2). Flood-frequency data for urban areas in Oklahoma are virtually nonexistent; therefore, the accuracy of the urban equations cannot be determined. The general form of the equations is

$$Q_x(u) = \frac{7R_xQ_2(R_L-1)}{6} + \frac{Q_x(7-R_L)}{6}$$

where $Q_{x(u)}$ is the urban peak discharge for recurrence interval, x; R_L is an adjustment factor to account for the effect of urban development; Q_x is the natural peak discharge for recurrence interval, x; Q_2 is the mean annual flood discharge for natural conditions; and R_x is the rainfall-intensity ratio for recurrence interval, x.

Classification: Statistical estimation of peak flow.

Location: Oklahoma.

99. Schaake, J. C., Jr., J. C. Geyer, and J. W. Knapp. 1967. Experimental examination of the rational method. Amer. Soc. Civil Engin., Jour. Hydraul. Div. 93(HY6): 353-370.

Abstract: Rainfall and runoff data collected in Baltimore, Md., from 20 gaged urban areas ranging in size from 1 to 150 acres are used in a study of the rational method. The results suggest the assumption that rain frequency equals runoff frequency may be nearly correct when an appropriate C value has been selected. Presently used values of C are not adequately based on measurements of rainfall and runoff in urban areas, so large errors can occur when the rational method is used. A test of user reproducibility is provided, with errors ranging from -46 to +61 percent.

Classification: Statistical estimation of peak flow.

Location: Maryland.

100. Sevuk, A. S., B. C. Yen, and G. E. Peterson. 1973. Illinois storm sewer system simulation model: User's manual. Ill. Univ. (Urbana-Champaign), Water Resour. Center Res. Rpt. No. 73.

Abstract: The University of Illinois storm sewer system simulation model is a flow routing model. Inflows to the modeled sewer network have to be provided in the form of hydrographs as input data. The flows are routed through a converging network of circular sewers with the equations for nonsteady gradually varied open channel flow.

Classification: Single storm event.

Location: Illinois.

101. Shih, G. B., E. K. Israelsen, R. N. Parnell, and J. P. Riley. 1976. Application of a hydrologic model to the planning and design of storm drainage systems for urban areas. Utah Water Res. Lab. (Logan) Rpt. No. PRWG 86-1, 79 pp.

Abstract: The hydrologic model described is a hybrid computer model where the various hydrologic function and routing functions are modeled. The unique features of this model are its ability to (1) accept a wide range of input hyetographs, (2) accommodate variable loss rates, (3) combine subzone hydrographs, and (4) combine watershed hydrographs into a single runoff function. Two urbanization characteristics, percent of impervious cover, and a characteristic impervious length factor were used to describe urbanization. Using regression analysis the urbanization parameters were used to describe interception storage capacity, depression storage capacity, and initial infiltration capacity. The hydrograph rise time was related to drainage area. The model was applied to three watersheds on an event basis.

Classification: Continuous record.

Location: Salt Lake County, Utah.

102. Skipwith, W. E., and W. L. Moore. 1976. Evaluation of urban runoff by watershed simulation. Tex. Univ. (Lubbock) Center Res. Water Resour. Tech. Rpt. CRWR-127, 121 pp.

Abstract: The University of Texas watershed simulation computer model was used to investigate the effects and characteristics of urban development in a small watershed. The primary objectives of the research were (1) to determine the significance and effects on streamflow of lawn irrigation in a small watershed containing a large amount of residential land use; (2) to evaluate the effect of urbanization on runoff from the watershed and the corresponding

change of the parameters in the watershed simulation program; and (3) to utilize the comparison of field measurements of soil moisture with simulated soil moisture values as an indication of the validity of the simulation program.

Classification: Continuous record.

Location: Austin, Tex.

103. Smith, M. E., and D. O. Doehring. 1969. A planning algorithm to assess the impact of urban growth on flood expectancy. Hydrol. Sci. Bull., In Symposium on the Effects of Urbanization on the Hydrological Regime and on Water Quality Proc., UNESCO, 12 pp. Amsterdam, Netherlands.

Abstract: Relationships that predict the change in discharge corresponding to both 1 and 2 percent exceedance probabilities on the basis of indices of urban land use changes, surficial properties of the catchment, and the configuration of the drainage network were presented. Flood expectancy for two distinct time frames was calculated by standard statistical analyses of annual maxima. The final algorithm developed by stepwise-multiple-regression technique utilized data from 18 basins in southeastern New England. The form of the equation was:

$$I_{h.50} = -0.76 + 7.1\ I_{\Delta u} + 1.25\ I_p + 0.87/E$$

where:

$I_{h.N}$ = index of absolute change in the N-year event in proportion to the pre-urban mean annual flood.

I_u = index of urbanization $= \Delta z/(A - z_2)*(1 - z_1/A)$

z = change in urbanization
A = basin area
Subscripts 1 and 2 refer to initial and final time frames, respectively.

I_p = pervious index $= P/(I - nS)$

P = area of pervious deposits,
I = area of impervious deposits,
S = area of swamp deposits and wetlands,
n = weighting factor to account for the differing hydrological response of the latter two surficial units.

E = measure of drainage network composition.

Classification: Statistical estimation of peak flow.

Location: Northeastern United States.

104. Snyder, F. F. 1958. Synthetic flood frequency. Amer. Soc. Civil Engin., Jour. Hydraul. Div. (HY5): 1-22.

Abstract: A procedure is developed for computing the flood discharge probability associated with a given rainfall-duration-frequency pattern on natural drainage basins, nonchannelized overland flow areas and areas with storm sewer drainage utilizing basin runoff-producing characteristics of area, length, slope, friction, and shape. The approach patterned after the so-called rational method utilizes the time of concentration concept with a unit hydrograph interpretation, but recognizes and evaluates separately the effect of storage existing in all types of channels or conduits and an average rainfall-runoff relation. The variable factors in this case were evaluated for application in the vicinity of Washington, D.C.

Classification: Single storm event.

Location: Washington, D.C.

105. Societe Grenobloise d'Etudes et d'Applications Hydraliques. 1973. Mathematical model of flow simulation in urban sewerage systems, CAREDAS Program. Grenoble, France.

Abstract: The Looped Sewer Model of the French consulting firm Societe Grenobloise d'Etudes et d'Applications Hydrauliques (SOGREAH) simulates the time-varying runoff of combined sewerage systems consisting of several catchments and a sewer and open channel network including loops and converging and diverging branches. The rational formula or the Horton equation can be used to compute the rainfall excess hyetograph. The rainfall excess hyetographs are then routed over each catchment to the sewer inlets using the Muskingum flood routing method. The formula considers the percent imperviousness and the overland flow length and slope. The formulations for the catchment runoff do not consider evapotranspiration, snow accumulation, and melt, and catchment moisture accounting during periods of no precipitation. Flow routing is accomplished with the dynamic wave equations for nonsteady gradually varied open channel flow.

Classification: Single storm event.

Location: France.

106. Spencer, D. W., and T. W. Alexander. 1978. Technique for estimating the magnitude and frequency of floods in St. Louis County, Missouri. U.S. Geolog. Survey (Rolla, Mo.), Water Resour. Invest. 78-139, 23 pp.

Abstract: Equations and nomographs were presented to estimate peak flood-discharges having recurrence intervals up to 100 years in rural and urban areas of St. Louis County, Mo. The basin characteristics significant at the 5-percent probability level were drainage area and percentage imperviousness. Channel slope was found to be insignificant at the 5-percent probability level. The equations for estimating peak flows took the form of a

linear relation between the logarithms of the independent variables. Drainage area was measured from maps, and percentage of imperviousness was measured from aerial photographs or estimated from land-use projections. The equations were based upon the analysis of hydrologic data collected at 20 continuous-recording gaging stations with drainage areas ranging from 0.8 to 39.0 square miles, and with impervious areas ranging from 1 to 32 percent.

Classification: Statistical estimation of peak flow.

Location: St. Louis Co., Mo.

107. Stankowski, S. J. 1974. Magnitude and frequency of floods in New Jersey with effects of urbanization. U.S. Geolog. Survey (Trenton , N.J.), Spec. Rpt. 38, 46 pp.

Abstract: Mathematical and graphical relations are presented to estimate flood-peak magnitudes having selected recurrence intervals ranging from 2 to 100 years for drainage basins larger than 1 square mile with various degrees of existing or projected urban and suburban development. Four parameters are required for use of the relations. Three of these may be measured from topographic maps; namely, basin size, channel slope, and surface storage within the basin. The fourth is an index of manmade impervious cover which can be determined for existing and future development conditions from census data and population projections that are readily available from regional, State, and local planning agencies. Developed from an analysis of flood information for 103 sites in New Jersey, the relations should be useful for design of bridge waterway openings, selection of optimum size for drainage structures, evaluation of flood hazards for alternative land-use plans, and for definition of floodway and flood-hazard-area limits.

Classification: Statistical estimation of peak flow.

Location: New Jersey.

108. Surkan, A. J. 1973. HYDRA: Dynamic model for urban hydrologic systems. Neb. Univ. (Lincoln), Department of Computer Science.

Abstract: The University of Nebraska Urban Hydrologic Simulator computes the time-varying runoff from several catchments and routes them through a converging closed conduit network. The model assumes that storm runoff is a constant fraction of the rainfall and that pipe flow velocities are a linear function of distance only.

Classification: Single storm event.

Location: Nebraska.

109. Sutcliffe, J. V. 1978. Methods of flood estimation: A guide to the flood studies report. Inst. Hydrol. (Wallingford, England) Rpt. No. 49, 50 pp.

Abstract: The guide is a summary of the five volume Flood Studies Report and covers statistical methods and unit hydrograph methods of flood estimation. Urbanization is accounted for by a percent development parameter which is used to the regression equations along with a soil index, rainfall index, slope, area, and a stream frequency. In the unit hydrograph method the urbanization parameter is used to determine the runoff volume.

Classification: Single storm event.

Location: England.

110. Terstriep, M. L. and J. B. Stall. 1969. Urban runoff by Road Research Laboratory Method. Amer. Soc. Civil Engin., Jour. Hydraul. Div. 95(HY6): 1809-1834.

Abstract: A simple mathematical model of an urban basin presented in 1962 by the British Road Research Laboratory is tested on three urban watersheds in the United States. The basins are located in Baltimore, Md., Chicago and Champaign, Ill., and 0.395, 12.5, and 2,290 acres, respectively. The model produces a runoff hydrograph by applying rainfall to only the directly connected impervious area of the basin. The basin is described by a time-area diagram and discharge-storage relationship. The peak discharges of actual and predicted hydrographs are compared for 39 storms and complete hydrographs are shown for 8 of these. To apply the model to a basin, the pattern of impervious areas must be known in detail, as well as the slopes and sizes of all surface and subsurface drains.

Classification: Single storm event.

Location: Champaign and Chicago Ill., and Baltimore, Md.

111. Terstriep, M. L. and J. B. Stall. 1974. The Illinois urban drainage area simulator. Ill. State Water Survey (Urbana, Ill). Bull. 58.

Abstract: The model based on a computer version of the British Road Research Laboratory Model computes the runoff from pervious areas and includes the option to either size circular sewers or retention basins.

Classification: Single storm event.

Location: Illinois.

112. U.S. Army Corps of Engineers. 1960. HEC-1, Flood hydrograph package. Hydrol. Engin. Center, Davis, Calif. 65 pp.

Abstract: HEC-1 is the first in a series of package programs developed by HEC to incorporate all the basic flood hydrograph computations associated with a single recorded or hypothetical storm into a single unit. The capabilities of the program are (1) hydrograph generation based on the unit hydrograph

approach, including unit hydrographs computed from time-area curves; (2) hydrograph combining and routing through channels and reservoirs via a number of alternate methods; (3) rainfall, snowfall, snowpack, and snowmelt determinations.

Classification: Single storm event.

Location: Entire United States.

113. U. S. Corps of Engineers. 1974. Urban runoff: Storage, treatment, and overflow model "STORM." Hydrol. Engin. Center Computer Program 723-S8-L2520, Davis, Calif.

Abstract: The Storage, Treatment, and Overflow Model (STORM) is intended primarily for evaluating stormwater storage and treatment capacity required to reduce untreated overflows below specified values. The model can simulate hourly stormwater runoff for a single catchment for several years. Hourly stormwater runoff is defined as the product of a runoff coefficient and hourly rainfall excess. Only one precipitation record can be used. The runoff coefficient is the weighted average of empirical runoff coefficients for the pervious and impervious areas and represents the fraction of rainfall excess lost to infiltration. The rainfall excess is defined as the difference between hourly rainfall and losses to depression storage. The depression storage at the beginning of a rainstorm is defined as the available depression storage at the end of the previous rainstorm plus a linear recovery to account for evaporation during the period of no precipitation. A different evaporation rate can be specified for each month of the year. Snowmelt is computed by the degree-day method. The runoff coefficients, available depression storage, and depression storage recovery factor have to be derived by calibration with observed data.

Classification: Single storm event.

Location: Entire United States.

114. U.S. Soil Conservation Service. 1969. Computer program for project formulation-hydrology. U.S. Soil Conserv. Serv. Tech. Release No. 20, Supplement No. 1, Washington, D.C.

Abstract: The program computes surface runoff resulting from any synthetic or natural rainstorms; develops flood hydrographs; routes through stream channels and reservoirs; and combines hydrographs with those from tributaries. Peaks and/or flood hydrographs, their time of occurrence, and water surface elevations at any desired cross section or structure are provided. The program was developed to analyze a watershed under present conditions and future conditions with combinations of land cover/use, structural or channel modifications or both. Input data requirements are storm rainfall depths, durations, and distributions; SCS runoff curve numbers; time of concentration; dimensionless unit hydrograph; reach lengths; convex method routing coefficients or elevation discharge-area data for cross sections; storage-

discharge data for reservoirs; baseflow. Runoff curve numbers are a function of land use and treatment or practice, hydrologic condition, hydrologic soil group, and antecedent moisture conditions. SCS project-size watersheds generally range from 1 to 400 square miles.

Classification: Single storm event.

Location: Entire United States.

115. U.S. Soil Conservation Service. 1975. Urban hydrology for small watersheds. U.S. Soil Conserv. Serv. Tech. Release No. 55, Washington, D.C.

Abstract: Three shortcut methods for estimating peak discharge on small watersheds, rural or urban, using SCS techniques are given. Chapter 5 presents the tabular routing method for developing a composite flood hydrograph at any point within a watershed, using subareas, time of concentration, reach travel times, and prerouted hydrograph unit discharge values. Chapter 5 also contains a graphical method to determine peak discharges given the time of concentration. Appendix D presents charts for estimating peak rates of runoff based on drainage area, slope, and curve number. Appendix E presents adjusting factors for slope interpolation, swampy and ponding areas, and watershed shape. Storm rainfall depth, SCS runoff curve numbers, time of concentration and travel times slope are input requirements. The SCS standard 24-hour, type II storm distribution is used in all three methods. The charts in appendix D are limited to drainage areas less than 2,000 acres. The size of watersheds used in the tabular method is limited to subarea time of concentrations less than 2 hours and travel times less than 4 hours to the watershed outlet. The graphical method limits time of concentration to less than 5 hours. The prerouted hydrograph table and the graph of peak vs. time of concentration were developed using SCS Technical Release No. 20 with a 0.1 time increment definition of the rainfall distribution.

Classification: Single storm event.

Location: Entire United States.

116. Viessman, W., Jr. 1968. Runoff estimation for very small drainage areas. Water Resour. Res. 4(1): 87-93.

Abstract: A function for peak discharge and a function relating flow with time, peak discharge, and recession constant are developed. The function is derived from impervious area data for K and tested on experimental agricultural plots, giving good unit hydrograph results. The equation is applicable primarily to urban areas. The single parameter that is required to define the unit hydrograph was found to be a function of Manning's roughness coefficient, the maximum gutter flow distance or flow length, and mean gutter slope.

Classification: Single storm event.

Location: Not specified.

117. Walesh, S. G., and R. M. Yidekovich. 1978. Urbanization: Hydrologic-hydraulic damage effects. Amer. Soc. Civil Engin., Jour. Hydraul. Div. 104(HY2): 141-155.

Abstract: A model used to determine the hydrologic-hydraulic flood damage effects of urbanization is described. The model consists of three submodels: Part 1, the Hydrocomp's hydrologic model; Part 2, the Corps of Engineers' steady-state backwater program; and Part 3, the Flood Economics Submodel developed by the Southeastern Wisconsin Regional Planning Commission. Seven floodplain urbanization configurations were selected to encompass the full spectrum of combinations that have existed or could exist in chosen watersheds located in southeastern Wisconsin. Assuming complete urbanization of the undeveloped floodplain and nonfloodplain, 100-year discharges may be expected to increase by factors of 1.4 to 6.4 based upon the results of the study.

Classification: Continuous record.

Location: Wisconsin.

118. Watkins, L. H. 1962. The design of urban sewer systems. Dept. Sci. and Indust. Res. (London, England), Road Res. Tech. Paper No. 55.

Abstract: The British Road Research Laboratory Model simulates the time-varying runoff in combined sewerage systems consisting of several catchments and a converging branch sewer and open-channel network. The model computes surface runoff only from impervious areas that are directly connected to the storm drainage system (flow does not pass pervious areas). The model is limited to the simulation of single runoff events. Storm runoff is computed from the weighted average rainfall of several raingages. Losses are subtracted from the rainfall according to a function of time which is defined as input data. The rainfall excess is routed to sewer inlets using average travel times computed for each hydrograph from Manning's equation. The combined flow is routed from each inlet through the sewers with a storage routing technique which uses average travel times computed for each inlet hydrograph from Manning's equation.

Classification: Single storm event.

Location: England.

119. Watt, W. E. 1975. QUURM - Queen's University Urban Runoff Model. Queen's Univ., Dept. Civil Engin., Kingston, Canada.

Abstract: The Queen's University Urban Runoff Model simulates the time-varying runoff in a combined sewerage system consisting of several catchments and a converging sewer network. Runoff is computed from rainfall

with the unit-hydrograph method and routed through the sewers with a simple time-offset method using Manning's equation.

Classification: Single storm event.

Location: Canada.

120. Weiss, L. A. 1975. Floodflow formulas for urbanized and nonurbanized areas of Connecticut. Amer. Soc. Civil Engin., Irrig. Drainage Div. Water Managt. Symposium, 18 pp.

Abstract: The area distribution of rainfall data for the 12-hour, 2-year, and 100-year frequencies and 24-hour, 100-year frequencies, and geometric parameters, such as drainage area, streambed slope, and stream length, are used as input to a regression analysis of annual maximum runoff for a given frequency. The ratio of the length of the stream divided by the square root of the stream slope is adjusted to account for the percentage of the storm sewers.

Classification: Single storm event.

Location: Connecticut.

121. Wibben, H. C. 1976. Effects of urbanization on flood characteristics in Nashville-Davidson County, Tennessee. U.S. Geological Survey (Reston, Va.), Water Resour. Invest. 76-121, 33 pp.

Abstract: Streamflow data from 14 basins in Davidson County were extended in time by use of a digital model of the hydrologic system. The basins ranged in size from 1.58 to 64.0 square miles and ranged in extent of man-made impervious cover from 3 to 37 percent. The flood-frequency characteristics were defined by weighting frequency curves based on simulated discharges with those based on observed discharges. The average record length of the three rain-gages used in simulation was 72 years and the average record length of observed discharges was 11 years. Discharges corresponding to 2-, 5-, 10-, 25-, 50-, and 100-year floods from the modeled basins were compared with discharges from regional equations for estimating peak discharge rates from rural basins. Lag times between rainfall and runoff in the urban basins were compared with those of nearby rural basins. The analyses indicated that in a fully developed residential area, the flood peaks and the basin lag times will not be significantly different from those expected from an undeveloped area. Data were not sufficient to determine if an increase in flood peaks would occur from extremely small basins with extremely intensive development.

Classification: Statistical estimation of peak flow.

Location: Tennessee.

122. Williams, K. K. 1979. Oklahoma City urban storm runoff quality: Comparison and calibration of predictive methods. Unpublished PhD Thesis, Oklahoma University, Norman.

Abstract: Six discrete event urban rainfall-runoff quantity models commonly used by federal agencies were calibrated on 23 events recorded by the U.S. Geological Survey on three urban basins during 1974-75 in Oklahoma City. The models were the Rational Method (Department of Housing and Urban Development), TR-20 (Soil Conservation Service), HEC-1 (Corps of Engineers), Urban Flood Hydrograph Snythesis Model (Geological Survey), SWMM (Environmental Protection Agency), and MINICAT (National Weather Service, River Forecast Center). All the models were calibrated for peak discharge on the recorded floods, and all except the Rational Method were calibrated for runoff volume. The calibrated models were compared on how accurately they reproduced the recorded hydrographs. Each model calibrated nearly as well as the others, except that HEC-1 was a little more reliable in reproducing the recorded events than the other models, and the TR-20 tends to bias, making the larger floods too large and the smaller hydrographs too small.

Classification: Single storm event and comparison.

Location: Oklahoma City, Okla.

123. Wilson, K. V. 1967. A preliminary study of the effect of urbanization on floods in Jackson, Miss. U.S. Geolog. Survey (Jackson, Miss.), Professional Paper 575-D, p. 259-261.

Abstract: Comparison of flood-frequency curves for three streams near Jackson, Miss., based on annual maximum floods for the period 1953-66, and for another stream for a shorter period, indicates that the mean annual flood for a totally urbanized basin is about 4-1/2 times that of a similar rural stream. It further indicates that the 50-year flood for such an urbanized basin is about 3 times that of a rural stream. The drainage area of these streams ranged from 1.12 to 11.3 square miles. The percentage of the basins with storm sewers and improved channels ranged from 20 to 50 percent.

Classification: Statistical estimation of peak flow.

Location: Jackson, Miss.

124. Wittenberg, H. 1975. A model to predict the effects of urbanization on watershed response. In National Symposium on Urban Hydrology and Sediment Control, Ky. Univ. (Lexington) Bull. 109, pp. 161-168.

Abstract: Storm runoff from partly urbanized catchments is not a homogeneous event. In general, it is the response of two different systems, i.e., pervious and impervious areas, to rainfall input. A model for the separation and simulation of these components was developed on the basis of two parallel

cascades of linear reservoirs. Optimum model parameters were found by a search technique for about 200 flood events in four catchments over a period of 21 years with increasing urbanization. Analysis of the parameters showed that the method is capable of predicting urbanization effects on watershed responses.

Classification: Single storm event.

Location: Germany.

125. Wright-McLaughlin Engineers. 1969. Urban storm drainage criteria manual. Denver Regional Council of Governments, Denver, Colo.

Abstract: A hydrologic design manual for Denver, Colo. is presented. The three basic approaches for determining the character of urban storm runoff are the rational method, the unit hydrograph-design rainfall method termed "Colorado Urban Hydrograph Procedure (CUHP)," and statistical analyses based upon actual recorded flood events from basins that will not undergo significant changes in the future. The rational formula is recommended for areas under 200 acres and Colorado unit hydrograph for areas over 200 acres. Statistical analysis is used for large streams in which future urbanization will have little effect on the runoff characteristics. The percent imperviousness was used to describe urbanization in the unit hydrograph model.

Classification: Single storm event.

Location: Denver, Colo.

126. Yen, B. C., A. O. Akan, V. T. Chow, and A. S. Sevuk. 1976. Prediction model for urban storm runoff. Amer. Soc. Civil Eng. Urban Water Resources Research Program Tech. Memo. No. 31, pp. 108-117, New York, N. Y.

Abstract: The model described used different rainfall hyteographs for different areas within the drainage basin. The Horton's formula is adopted to evaluate infiltration and overland flow is computed by using the kinematic wave method, together with the Darcy-Weisbach formula to estimate the friction slope. The gutter flow is computed by using the kinematic wave method together with Manning's formula to estimate the friction slope. Catch-basin inlets are classified according to their hydraulic and geometric characteristics. The sewer flows are computed by solving numerically the complete St. Venant equations and accounting for both the upstream and downstream backwater effects due to junctions and manholes. Flow-control facilities of a sewer system are accounted for by including the mathematical functions representing their hydraulic characteristics. The outputs of the model are time distributions of the runoff rate, flow depth, and pollutant concentration at various specified or desired locations of the drainage system. The model is physically based and requires no calibration.

Classification: Single storm event.

Location: Entire United States.

127. Yorke, Thomas H., and Herb, William J. 1978. Effects of urbanization on streamflow in the Rock Creek and Anacostia River Basins, Montgomery County, Maryland, 1962-74, U.S. Geol. Survey (Reston, Va), Prof. Paper 1003, 71 pp.

Abstract: Land use/land cover, precipitation, streamflow, and sediment data were collected from nine drainage subbasins in a 32-square mile (83 square kilometer) area north of Washington, D.C., in Montgomery County, Md. This study was begun in 1962 to define urban runoff and sediment problems and was expanded in 1966 to evaluate response to sediment-control practices in areas undergoing urban development. Land use/land cover varied considerably in the study subbasins, which ranged in size from 0.35 to 21.1 square miles (0.91 to 54.6 square kilometers). Three subbasins remained virtually rural, while the others underwent urban development. In 1974, urban land represented from 0 to 60 percent of the land use in the nine subbasins. Urbanization did not affect median and low flows, but did increase storm runoff and peak discharges.

Classification: Assessment of data.

Location: Montgomery County, Md.

128. Zeller, M. E. 1977. Prediction of peak discharges from surface runoff on small semiarid watersheds for 2-year through 100-year flood recurrence intervals. In A Hydrology Manual for Engineering Design and Flood Plain Management within Pima County, Ariz. Pima County Highway Department, Tucson, Ariz.

Abstract: A semi-empirical model based on a time of concentration concept. The equation used is:

where T_c is in hours, and:

n_b = A dimensionless constant that represents the visually estimated mean of the "n-factor", or roughness coefficient, of all principal watercourses within a watershed, hereafter to be referred to as the "basin factor."

L_c = The length of the longest watercourse within the watershed, in feet, measured from outlet to divide.

L_{ca}= The distance up the longest watercourse, in feet, from the outlet to a point opposite the center of gravity of the watershed.

S_c = The mean slope, in feet/feet, of the longest watercourse within the watershed, as determined by the "incremental" or "uniform slope" method.

q = The runoff supply rate, in inches/hour.

50 = A conversion factor whose units are $ft^{.6}/in^{.4}$-$hr^{.6}$.

The determination of T_c is an iterative process between T_c and q. The runoff supply rate is based on SCS curve numbers and the rainfall depth for the frequency storm under investigation. Once the correct q is determined, the peak flow is determined by using the following equation:

$$Qp = 645.33\ qA.$$

A = area of watershed is square miles. Detailed instructions for determining all parameters in the methods are given.

Classification: Single storm event.

Location: Pima County, Ariz.

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